SOIL NITROGEN CONTENTS AND CLASSIFICATION OF SELECTED POST-FIRE SITES IN THE SUB-BOREAL SPRUCE ZONE OF CENTRAL BRITISH COLUMBIA

by

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ABSTRACT

Short and long term planning for sustainable forest management is beset by limited knowledge about the soils and their properties. This thesis was conducted in the McGregor Model Forest to provide relevant information on the types and nitrogen contents of selected soils in the very wet, cool Sub-boreal Spruce biogeoclimatic subzone in the central interior of British Columbia. Thirteen post-fire sites were selected and grouped as Early Seral (four sites < 14 years post-fire), Mid-Seral (five sites 50 - 80 years post-fire) and Late Seral (four sites > 140 years post-fire). Fifteen pedons were sampled and analyzed for physical and chemical properties as well as the contents of total nitrogen, mineralizable nitrogen, available nitrate and ammonium.

Five pedons were classified as Eluviated Dystric Brunisols, two as Gleyed Eluviated Dystric Brunisols, five as Orthic Humo-Ferric Podzols, two as Orthic Gray Luvisols, and one as a Rego Humic Gleysol. Incipient podzolization seems to be the dominant pedogenic process in the area along with clay movement (lessivage) and minor hydromorphic processes. With time, it is anticipated that four of the Eluviated Dystric Brunisols will develop into Porthic Humo-Ferric Podzols and the fifth will become an Orthic Gray Luvisol. The three gleyed pedons were the result of changes in microtopography.

Total N ranged between 0.012 - 0.59% and 0.45 - 2.6% in the mineral and forest floor horizons, respectively, with no significant difference observed between the age classes. Mineralizable N ranged between 11.2 - 146 ppm in the mineral horizons and 308 - 2044 ppm in the forest floor. Available ammonium ranged from 1.4 - 25.3 ppm (mineral horizons) and 23.2 - 647 ppm (forest floor horizons). Both available ammonium and mineralizable N levels were highest in

the forest floor horizons of the Mid-Seral sites. Available nitrate ranged from 0.005 - 27.6 ppm and 0.005 - 209 ppm in the mineral and forest floor horizons, respectively. With time, available nitrate approaches an equilibrium level as indicated by the decrease in the concentration ranges from the Early Seral to the Late Seral age classes. Where significant differences were noted in the mineralizable and available nitrogen analyses, the Early Seral age classes were generally separated from the older age classes.

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Chapter One - INTRODUCTION

1.1 Rationale

Forestry is vital to the economic future of the central interior of British Columbia. If it is not managed in a sustainable manner, the livelihoods of many people will suffer. Forest soil, in addition to being a key attribute in determining the ecological quality of a forest site, is essential to the sustainability of timber extraction and forest productivity and is not renewable in the short-term (Kimmins, 1997; Klinka *et al.*, 1994). Knowledge of soil properties is critical in the short and long term planning of forest industry operations such as harvest scheduling and conservation plans, as is the soil's capacity for recovery of its nutrient base following forest fires and other disturbances (Kimmins, 1996).

Information regarding soils in the Prince George Forest Region is very sparse. The British Columbia Soil Survey is far from complete and does not provide sufficient information upon which management decisions may be made (Driscoll, 1996). Forest floor and soil survey data (combined with information on the nitrogen characteristics of the dominant horizons therein) may be used in assessing the nitrogen fertility of different ecosystems (Fyles *et al.*, 1991b). By presenting baseline information on the types of soils found in this region and the levels of nitrogen, perhaps the most limiting of nutrients in British Columbia's Central Interior, forest practitioners in this region have more information upon which to base forest management decisions.

Two phases of analysis are used in the presentation of my research: (1) classification of the soils, and; (2) quantification of the concentrations of the various forms of nitrogen (total nitrogen, carbon/nitrogen ratio, available ammonium and nitrate, mineralizable nitrogen). The classification phase describes the soils that are found within the very wet, cool Sub-boreal Spruce biogeoclimatic subzone (SBSvk1) within the McGregor Model Forest. The soils are classified to the subgroup levels with full physical, chemical and morphological data provided. The second phase examines nitrogen dynamics as they occur following stand replacement by forest fires. A retrospective approach is used which presents patterns of change in nitrogen levels as the forest undergoes succession.

Since soil survey information is a critical component of land management decisions that use geographic information systems (GIS) (Maclean *et al.,* 1993), available information has been digitized and is presented as an ARC/INFO database in this thesis. However, much of this information is presented in medium scale maps, generally between 1:100,000 and 1:250,000 (e.g. Dawson, 1989), which cannot account for the heterogeneity of the soils being described. This study also expands upon this knowledge base by providing ground-proofed, site-specific data through the classification of pedons from the 13 study sites using the Canadian System of Soil Classification (Canadian System) and the USDA Soil Taxonomy (Soil Taxonomy).

The primary advantage of the Canadian System is its bias towards soil genesis; the names of the orders provide natural groupings of soils with similar characteristics and properties (Agriculture Canada Expert Committee on Soil Survey, 1987). The Soil Taxonomy, which is similar to the Canadian System, uses a taxonomic approach to soil classification which provides detailed descriptions of the soils within their classification names (Soil Survey Staff, 1994). This system is widely used in the United States and outside North America by countries which do not have their own system of soil classification since it can be used in the classification of all types of soil, whether or not found in the United States (Buol *et al.,* 1989; Soil Survey Staff, 1994; Yaalon, 1995).

This thesis will help to illustrate the important role fire plays in nutrient cycling in northern coniferous forests and its effect on nitrogen levels on the forest floor and within the mineral horizons. In a region which relies heavily on the sustainable growth of trees for economic survival, increased knowledge of nitrogen cycling can aid in determining which management practices are sound and should be followed. For example, linking the length of time following a forest fire to nitrogen levels may aid in determining the most appropriate time for planting or in preparing the appropriate nutrient mixture for the seedling plugs. As an essential nutrient, nitrogen is vital to the development of all plants; it is an integral component of chlorophyll and enzymes, a component of amino acids and the proteins required for the genetic development of plant tissue, cell nuclei and protoplasm (Brady, 1990). In boreal and cool temperate forests, nitrogen may be deficient because of slow decomposition, mineralization and cycling caused by low soil temperatures or poor drainage (Kimmins, 1996). Few studies have investigated nitrogen cycling in the central interior of British Columbia resulting in a paucity of data from which to assist in forest management decisions.

The relationships between the various soils and the levels of different nitrogen forms for each site should lead to a projection of nitrogen activity in similar areas within the model forest region. A cursory examination of the variations found in the different levels of nitrogen based on the vegetation present at the study sites is also undertaken. It is believed that the relationship between vegetation species composition and nitrogen turnover should be fairly constant within an ecosystem (Zak *et al.*, 1986), thus allowing for the extrapolation of data from point sources to a landscape level. By conducting nitrogen analyses on selected sites within the very wet, cool Sub-boreal Spruce biogeoclimatic subzone, it should be possible to present a picture of the nitrogen dynamics within these areas.

1.2 Research Objectives

1. To determine the physical, chemical and morphological characteristics of selected post-forest fire soils within the SBSvk1 in the McGregor Model Forest in order to classify them according to the *Canadian System of Soil Classification* (Agriculture Canada Expert Committee on Soil Survey, 1987) and the *Keys to Soil Taxonomy* (Soil Survey Staff, 1994) and compare their properties with other soils.

2. To determine the contents of total N, mineralizable N, available ammonium and nitrate of the forest floor and mineral horizons in order to determine the site quality of each soil and to investigate post-fire soil nitrogen dynamics as related to forest stand age.

1.3 Research Hypotheses

Results of the soil classification will be based on descriptive data obtained through field descriptions and laboratory analyses. The nitrogen analyses will include a presentation of the data obtained as well as an investigation of the content of total nitrogen, potential mineralizable nitrogen, available ammonium and available nitrate within the mineral and forest floor horizons of selected post-fire soils. The interaction between horizons and age classes is also investigated. The hypotheses are:

Ho_1: *There is no difference in total nitrogen, mineralizable nitrogen, available ammonium and nitrate, levels between the different age classes of each horizon.*

HA_1: *There is a significant difference in total nitrogen, mineralizable nitrogen, available ammonium and nitrate, levels between the different age classes of each horizon.*

Ho_2: *There is no interaction between the content of total nitrogen, mineralizable nitrogen, available ammonium and available nitrate levels of the mineral and forest floor horizons and the different age classes.*

HA_2: *There is a significant interaction between the content of total nitrogen, mineralizable nitrogen, available ammonium and available nitrate levels of the mineral and forest floor horizons and the different age classes.*

Chapter Two - STUDY AREA AND CHARACTERISTICS

The study sites are located on the McGregor Plateau in the Central Interior of British Columbia Details of the locations of the study sites have been provided in Table 2.1. This sub-boreal, montane area is bounded to the east and north by the Rocky Mountains, to the west by the Fraser Basin and to the south by the Nechako Plateau. The surficial geology, soil series, vegetation inventory and biogeoclimatic classification of the sites are described in this chapter.

Table 2.1 Locations of study sites.

Site #	Latitude (N)	Longitude (W)	Elevation (m.a.s.l.)	Slope (%)	Aspect (°)
1	54°20.2	122°10.6	930	50	164
2	54°20.2	122°10.6	940	15	194
3	54°19.5	122°15.2	820	37	0
4	54°21.7	121°59.9	870	30	32
5	54°23.7	122°13.5	1010	63	230
6	54°23.7	122°13.6	1010	58	60
7	54°20.2	122°12.0	1070	5	250
8	54°24.0	122°13.5	1040	37	290
9	54°05.7	121°29.3	1020	34	200
10	54°22.8	122°08.6	850	16	50
11	54°44.1	122°12.8	1160	50	180
12	54°44.2	122°12.2	1160	50	180
13	54°08.8	121°10.9	890	55	0

2.1 Surficial Geology

This study area has undergone many changes since the beginning of the Pleistocene (c. 1.65 Ma - 10 ka). Little now remains of the Pleistocene sediments within the interior of British Columbia as they are generally considered to have been scoured away during the advance and retreat of the ice sheet and glaciers of the Fraser Glaciation (c. 23-10 ka) or are covered by thick drift (Clague *et al.*, 1990). Pleistocene sediments are generally found in areas where bedrock projections deflected glacier advances and retreats, thus sheltering downstream areas from glacial scouring. Sedimentary layers along the margins of glaciers and the Cordilleran Ice Sheet also may have been protected because of the sluggish ice flow in the areas (Ryder and Clague, 1989).

Much of the surficial material currently found within the interior of British Columbia is the result of sediments and till laid down at the close of the Fraser Glaciation. The primary sources of this material were the Rocky and Mackenzie Mountains (Clague, 1989c).

The three major different types of surficial material of the study area are: glacial lacustrine, glacial fluvial and colluvium. These are all common to the Cordillera. Glacial lacustrine deposits are remnants of glacial lakes which had received outwash from glacial streams. The sediments which are indicative of a glacial lacustrine past are well stratified and include fine sand, silt and clay. Well defined stratification of this material is demonstrative of a process of sedimentation occurring during relatively stable conditions (Clague, 1989a).

Glacial fluvial deposits are formed by streams which were established from glacial meltwater. Features such as kames, kame terraces, kettle lakes and eskers are all indicative of a glacial fluvial history and are found in many areas within the McGregor Model Forest. Glacial fluvial deposition may be distinguished by thin continuous sheets of gravel and sand overlying a layer of till. Glacial fluvial layers also may be found beneath till layers in cases where evidence of older Pleistocene glaciations are still prevalent (Clague, 1989b)

Colluvial deposits occur as a result of mass wasting processes and are commonly found as surficial material in the Cordilleran region of British Columbia. Clague (1989a) discussed four major types of colluvium which are indicative of the central interior: landslide deposits, talus, colluviated drift and solifluction. The landslide deposits and colluviated drift are of particular interest as these features are found at our study sites. Landslide deposits have the greatest variation of texture and mass of the different colluvial deposits. They may occur as fine grained material from glacial lacustrine sediments or as coarse, blocky accumulations of broken rock. While landslides may occur in any part of the Cordillera, they tend to be relatively small in total size, representing less than one percent of the total surface area. Colluviated drift is a glacial deposit which has been transformed by sheet erosion and creep. This material forms thin mantles of diamicton and poorly sorted gravel on moderate and steep slopes. Areas of colluvial drift do exist within the area, however, our observations agreed with those of Clague (1989a) in that the colluvial deposits exist as secondary features within the bounds of other more dominant forces.

2.2 Soil Series of the Study Areas

Examination of 1:50,000 soils and surficial geology/landform maps indicated that the 13 study sites belonged to 10 different soil associations on four different map sheets. The locations and selected properties of these associations are provided in Table 2.2. The map provided as Appendix A shows the locations of the soil complexes within the McGregor Model Forest.

Sites 1, 2, 3, 4, 5, 6, 7 and 8 belong to a combination of the Averil and Dominion Soil Series (Dawson, 1989; Ministry of Forests, 1977). Averil Association soils are shallow soils of the Fraser Plateau dominated by Orthic Humo-Ferric Podzols. Gravelly sand is common (Dawson, 1989;

Ministry of Forests, 1977; Watt, 1980). The Dominion Association is also formed upon glacial materials. Dominion Soils are generally gravelly and loamy having developed on morainal materials. These soils are well drained and classified as Luvisolic Humo-Ferric Podzols (Lord, 1984; Watt, 1980).

Sites 10 and 13 were mapped as part of the Captain Creek Association in combination with other soil series. These are loamy soils developed on morainal materials. These soils are moderately well drained and have perhumid moisture regimes. Orthic Humo-Ferric Podzols are common as well as Podzolic Gray Luvisols to a lesser extent (Dawson, 1989; Lord, 1984; Ministry of Forests, 1977; Watt, 1980). The other series in combination with the Captain Creek Association at Site 10 is the Bearpaw Ridge Association. These sandy and loamy soils developed on colluvial deposits and are moderately well drained occurring under humid moisture conditions. Orthic Humo-Ferric Podzols again are the dominant classification, however, Eluviated Dystric Brunisols are also common (Dawson, 1989; Lord, 1984; Ministry of Forests, 1977).

At Site 13, the Dezaiko Association occurs with the Captain Creek Association. The Dezaiko Association is characterized by loamy and sandy soils developed on shallow colluvial or morainal deposits. These soils are well to moderately well drained and have humid to subhumid moisture conditions. They are found at higher elevations, generally above 1500 metres. Again, Orthic Humo-Ferric Podzols are the common classified soils (Lord, 1984; Watt, 1980).

Sites 11 and 12 belong to the Barton Soil Series which is characterized by Orthic Ferro-Humic Podzols formed of rubbly, silty colluvium occurring at various depths over metamorphic rock (Ministry of Forests, 1977).

Table 2.2 Soil associations and selected properties determined for each of the study sites.

Site	Soil Associations		NTS Map	ARC/INFO Polygon	Dominant Classification	Parent Material	Particle Size Class	Drainage
1	Dominion 2 (80%)	Averil 1 (20%)	93J/8	260	P.GL/O.HFP	morainal/ colluvial	gravelly loam/ gravelly sand	moderately well to well
2	Dominion 2 (80%)	Averil 1 (20%)	93J/8	260	P.GL/O.HFP	morainal/ colluvial	gravelly loam/ gravelly sand	moderately well to well
3	Dominion 2 (60%)	Averil 1 (40%)	93J/8	203	P.GL/O.HFP	morainal/ colluvial	gravelly loam/ gravelly sand	moderately well to well
4	Dominion 2 (70%)	Averil 1 (30%)	93I/5	118	P.GL/O.HFP	morainal/ colluvial	gravelly loam/ gravelly sand	moderately well to well
5	Averil 1 (70%)	Dominion 2 (30%)	93J/8	232	O.HFP/P.GL	colluvial/ morainal	gravelly sand/ gravelly loam	moderately well to well
6	Averil 1 (70%)	Dominion 2 (30%)	93J/8	232	O.HFP/P.GL	colluvial/ morainal	gravelly sand/ gravelly loam	moderately well to well
7	Averil 1 (80%)	Dominion 2 (20%)	93J/8	216	O.HFP/P.GL	colluvial/ morainal	gravelly sand/ gravelly loam	moderately well to well
8	Averil 1 (70%)	Dominion 2 (30%)	93J/8	232	O.HFP/P.GL	colluvial/ morainal	gravelly sand/ gravelly loam	moderately well to well
9	Torpy River 2 (50%)	Dome Creek 1 (50%)	93I/3	15	O.HFP/E.DYB	morainal/ colluvial	gravelly loam/ loam	moderately well to rapid
10	Bearpaw Ridge (70%)	Captain Creek (30%)	93J/8	257	O.HFP	colluvial/ morainal	gravelly sandy loam/ gravelly loam	well to moderately well
11	Barton 5 (100%)		93J/9	n/a	O.FHP	colluvial	rubbly silt	moderately well
12	Barton 5 (100%)		93J/9	n/a	O.FHP	colluvial	rubbly silt	moderately well
13	Dezaiko 2 (60%)	Captain Creek 2 (40%)	93I/3	n/a	O.HFP	colluvial/ morainal	gravelly sandy loam/ gravelly loam	well to moderately well

from Dawson, 1989; Driscoll, 1996; Lord, 1984; Ministry of Forests, 1977; Watt, 1980. E.DYB = Eluviated Dystric Brunisol, O.FHP = Orthic Ferro-Humic Podzol, O.HFP = Orthic Humo-Ferric Podzol, P.GL = Podzolic Gray Luvisol

Site 9 is a combination of Dome Creek and Torpy River Soil Associations. The Torpy River Association has developed gravelly and loamy soils on morainal materials. While Orthic Humo-Ferric Podzols are found in the well to moderately well drained areas, gleyed soils and Ferro-Humic Podzols may also be found (Lord, 1984; Watt, 1980).

2.3 Biogeoclimatic Ecosystem Classification

The study sites are located within the McGregor Model Forest in the Sub-boreal Spruce (SBS) biogeoclimatic zone. The locations of our study sites and the different biogeoclimatic subzones within the McGregor Model Forest are indicated in Figure 2.1. (Note: Due to mapping limitations, sites 9 and 13 appear to be within the ICH biogeoclimatic zone, however, site indicators were representative of the SBSvk and this becomes apparent on a larger scale map.) The SBS zone is dominated by gently rolling montane terrain of the Nechako and Fraser plateaus as well as the Fraser Basin. The maximum elevation ranges are between 1100-1300 m.a.s.l. where the Engelmann Spruce-Subalpine Fir (ESSF) zone begins (Meidinger *et al.*, 1991). This zone is characterized by seasonal extremes in temperature with severe winters and warm summers; the mean annual temperature ranges from 1.7-5°C. Precipitation is moderate ranging from 440-900 mm with 25-50% falling as snow. Monthly normals for temperature (Figure 2.2) and monthly normals for precipitation (Figure 2.3) have been compiled from the Environment Canada Climate Normals for four weather stations within this zone: Aleza Lake, McGregor, McLeod Lake and Prince George International Airport (Environment Canada, 1982). Note that the mean monthly temperatures are below the freezing point for five months of the year and that this is the same period in which the igure 2.1 Location of study sites in and around the McGregor Model Forest.

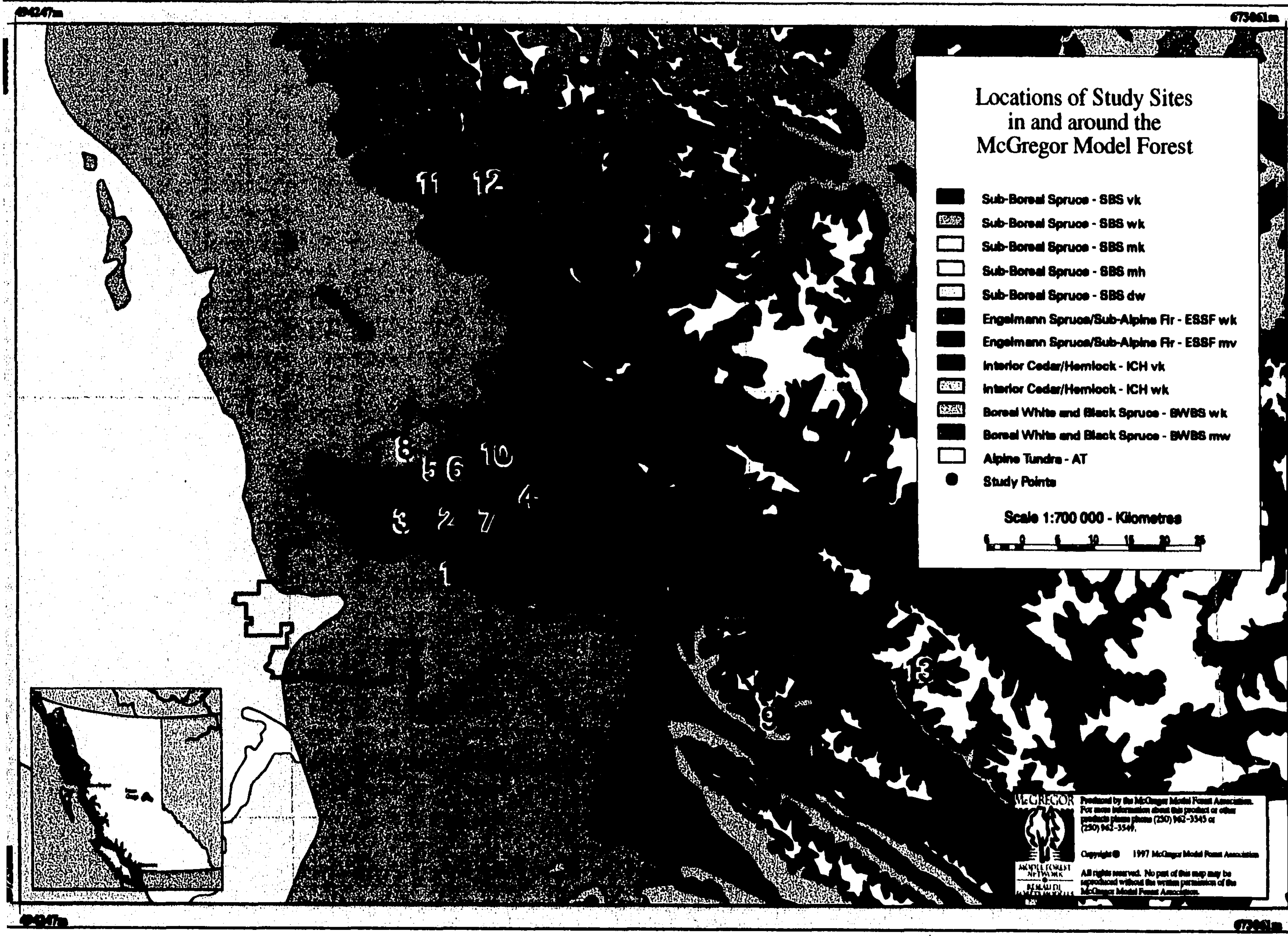


Figure 2.2 Mean monthly temperature values for selected sites in the McGregor Model Forest and surrounding area.

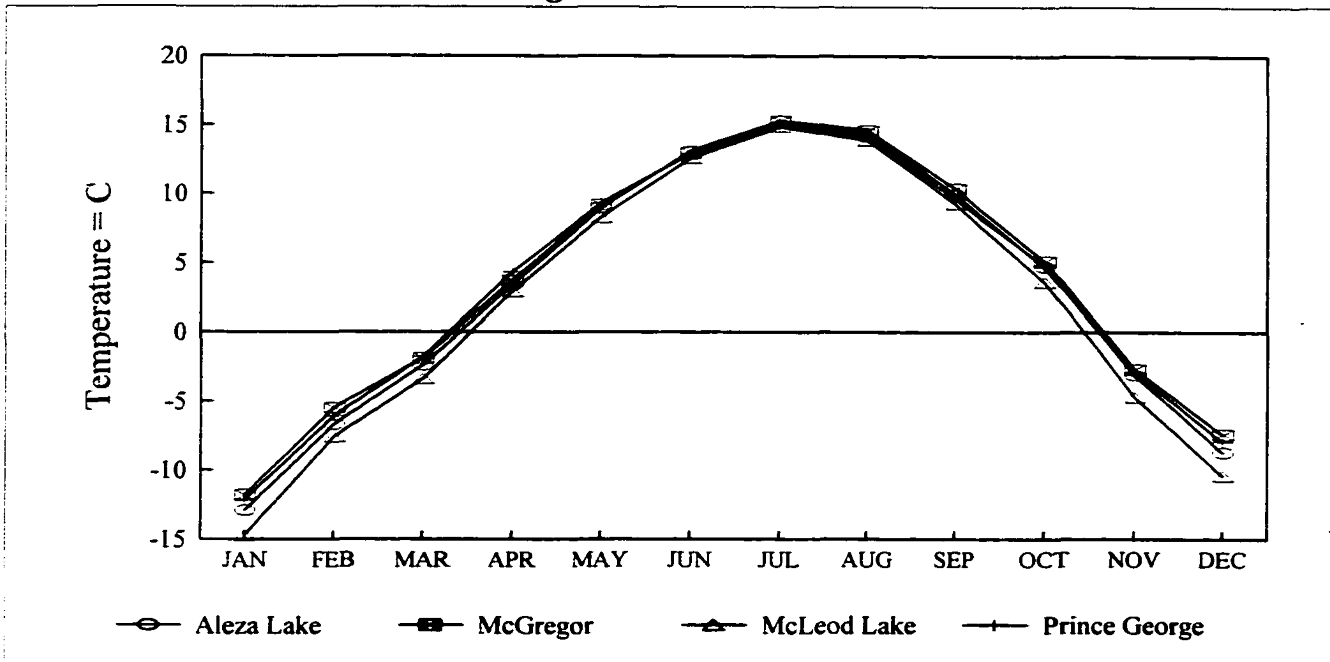
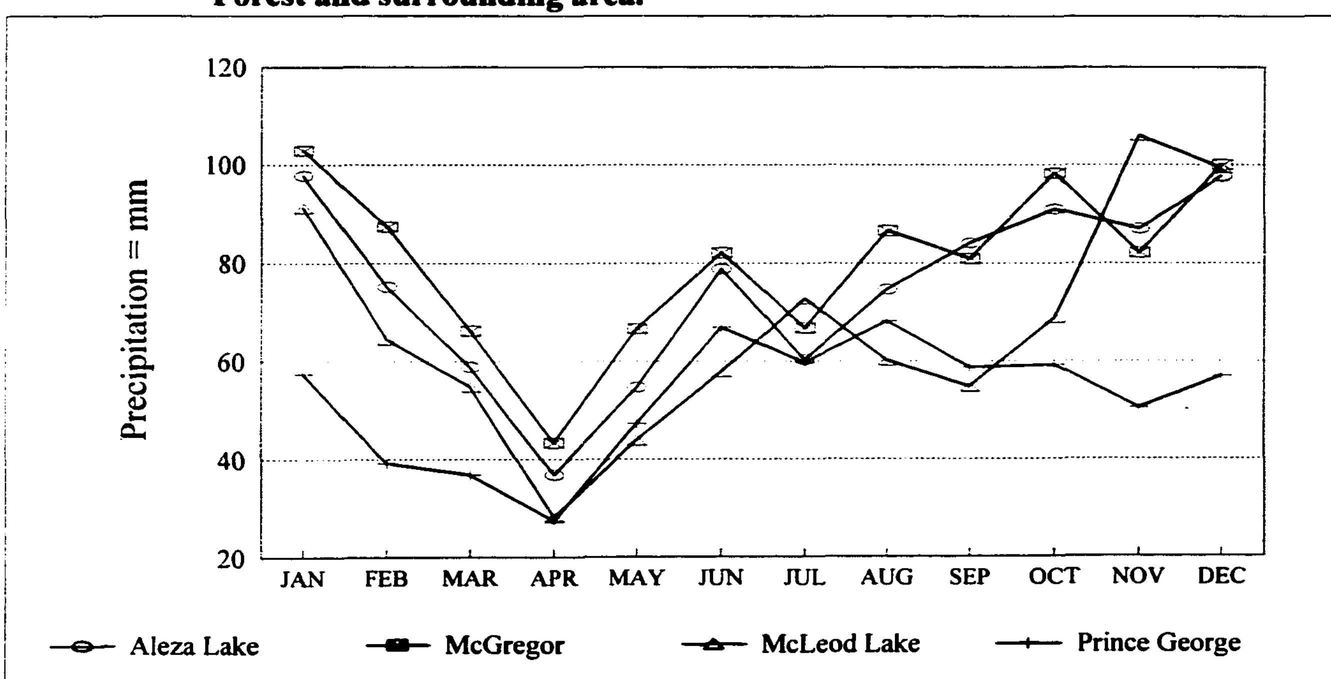


Figure 2.3 Monthly mean precipitation values for selected sites in the McGregor Model Forest and surrounding area.



highest precipitation means are recorded, predominantly as snow.

More specifically, the study sites were located in the very wet, cool Sub-boreal Spruce biogeoclimatic subzone (Meidinger and Pojar, 1991; Pojar *et al.*, 1987). The soil moisture and temperature regimes are categorized as humid to subhumid cryoboreal (Clayton *et al.*, 1977). The dominant soils in the SBS are Luvisols, Podzols and Brunisols. Imperfectly drained areas may be characterized as Gleysols (Meidinger *et al.*, 1991).

The SBSvk1 subzone typically is characterized by devil's club (*Oplopanax horridus*) and leafy mosses (*Mnium* spp.) with an overstory of hybrid white spruce (*Picea glauca x engelmannii*). Other indicator species of this zone are oak fern (*Gymnocarpium dryopteris*), thimbleberry (*Rubus parviflorus*), five-leaved bramble (*Rubus pedatus*) and three-leaved foamflower (*Tiarella trifoliata*)(Meidinger *et al.*, 1991). All vascular plant species and bryophytes occurring in the 30 x 30 m plots of study sites 1 - 12 were recorded as a percent of area covered by the McGregor Model Forest Ecological Processes Team and are presented in Table 2.2. (Site 13 was selected to fulfill statistical requirements for the soil nitrogen analysis and was not necessary for the vegetation inventory and, thus, no species list is available.)

Table 2.3 Inventory of vegetation for sites 1-12. Values presented as a percentage of the area covered of the study quadrats.

	Early Seral			Mid-Seral					Late Seral			
Trees	Site 5	Site 6	Site 9	Site 1	Site 3	Site 7	Site 10	Site 11	Site 2	Site 4	Site 8	Site 12
Abies lasiocarpa (Hook.) Nutt. [1]		0.1		5	5	5	20	2	20	15	30	2
Picea glauca (Moench) Voss x *Picea engelmannii* Parry ex Engelm.		0.1		20	15	40	40	10	50	25	54	30
Populus tremuloides Michx.	1											
Betula papyrifera Marsh.												1
Shrubs												
Abies lasiocarpa (Hook.) Nutt.	0.1			5	5	10	1	15	2	10		15
Acer glabrum Torr.					3			0.1		3		
Actaea rubra (Ait.) Willd.	1			1		1	5	0.1	0.1	1	2	
Alnus tenuifolia Nutt.				5							2	
Amelanchier alnifolia Nutt.		0.1										
Aruncus dioicus (Walt.) Fern.	1	3		2			0.5	1	3	3		
Betula papyrifera Marsh.								3				
Cornus stolonifera Michx.								0.5				
Lonicera involucrata (Rich.) Banks		7	2	2	5	3	2	1	3	3		
Oplopanax horridum (Smith) Miq.			0.1	3			70	20	30	70	65	6
Picea glauca (Moench) Voss x *Picea engelmannii* Parry ex Engelm.	0.1		15	10	2	5	0.5		3	5		4
Populus tremuloides Michx.		0.5	2									
Rhododendron albiflorum Hook.		15										
Ribes lacustre (Pers.) Poir.		2			1	1	2	0.5		0.1	0.5	0.1
Ribes laxiflorum Pursh	1	1										
Ribes oxyacanthoides L.									0.1			
Rosa acicularis Lindl.		0.1										
Rubus idaeus L.	3	2	5									
Rubus parviflorus Nutt.	35	7	20	10	10	5	5	1	5	2	20	

Rubus pubescens Raf.	10	0.1	2	1							1	
Salix spp.		0.1	1			1						
Sambucus racemosa L.	3	2	2			1	7				7	
Sorbus scopulina Greene		5	1	1	2	1	3			1		0.1
Spiraea betulifolia Pall.												0.1
Spiraea douglasii Hook.						1						
Thuja plicata Donn.			3									
Vaccinium membranaceum Dougl.		0.1	2	20	25	25	0.1	7	1	1		0.1
Vaccinium ovalifolium Smith	1	0.5	1	30	40	30			15	10	5	0.1
Viburnum edule (Michx.) Raf.		1		1	2	2		0.1	0.1	1		0.1
Herbs												
Aconitum delphiniifolium DC.								0.1				
Anaphalis margaritacea (L.) B. & H.	1	5	20									
Aquilegia formosa Fisch.				0.1								
Aralia nudicaulis L.					0.1			6				6
Athyrium filix-femina (L.) Roth.			2	0.1			7	5	1	10	10	
Calamagrostis canadensis (Michx.) Beauv.	2											
Calamagrostis rubescens Buckl.		3	5									
Carex mertensii Prescott	2	0.5	2									
Carex spp.		0.1										
Castilleja miniata Dougl.			0.1									
Cinna latifolia (Trevir.) Griseb.			3				0.1				0.1	
Circaea alpina L.							1			0.1		
Cirsium arvense (L.) Scop.	0.1											
Clintonia uniflora (Schult.) Kunth.	3	1	5	1	3	3		3		2	1	1
Cornus canadensis L.	2	2		5	10	10		15	3	1		9
Danthonia intermedia Vasey		2	1									
Disporum hookeri (Torr.) Nicholson												4
Dryopteris assimilis S. Walker	2	3			0.1	2	20	3	20	20	20	

Dryopteris expansa (K.B. Presl) Fraser-Jenkins & Jermy												6
Epilobium angustifolium L.	60	55	60		0.1	0.1		0.1	0.1		0.1	
Equisetum arvense L.		0.5				0.1			0.1			
Equisetum pratense Ehrb.								0.5				
Equisetum sylvaticum L.									0.1			
Galium triflorum Michx.	3	2	1				3	0.5		1	1	
Goodyera oblongifolia Raf.								0.5				
Gymnocarpium dryopteris (L.) Newm.	2	30	2	3	2	15	15	5	10	35	60	0.1
Heracleum sphondylium L.								0.5				
Hieracium albiflorum Hook.		0.1	3									
Hieracium aurantiacum L.		0.5										
Hieracium gracile Hook.	0.1											
Hieracium umbellatum L.			2									
Listera cordata (L.) R. Br.					0.1	0.1				0.1		
Lycopodium annotinum L.												2
Orthilia secunda (L.) House			0.1	0.1				0.1				0.1
Osmorhiza chilensis H. & A.							0.5				0.1	
Osmorhiza purpurea (Coult. & Rose) Suksd.									0.1			
Platanthera obtusata (Banks ex Pursh) Lindl.	0.1	0.1										
Pteridium aquilinum (L.) Kuhn.				1			1					
Rubus pedatus J.E. Smith					5	23		5	1	5	15	0.1
Senecio triangularis Hook.						0.5	0.5					
Smilacina racemosa (L.) Desf.			1	1			2	0.1		0.1	1	1
Streptopus amplexifolius (L.) DC.	1			2	1	2		0.1	1		1	0.1
Streptopus roseus Michx.	3	1	1	1	1	4	3	3		2	2	
Thalictrum occidentale Gray								1				
Thalictrum venulosum Trel.				0.1								
Thalictrum spp.		0.1			1	0.1			0.1			
Tiarella trifoliata L.				0.1			2	5		0.1	4	5
Tiarella unifoliata (Hook.) Kurtz.	1	1	3	2	3	7	12	1	1	2	10	

Urtica dioica L.							1				0.1	
Valeriana sitchensis Bong.					10	20			1	0.1		
Veratrum viride Ait.	15	10	1	2	5	2			2	7	5	
Viola adunca Sm.		0.1										
Viola canadensis L.										0.1	0.1	
Viola glabella Nutt.			0.1				1		0.1			
Viola spp. L.		0.1						0.5				
Mosses												
Brachythecium hylotapetum **B. Hig. & N.Hig.**					5		1				10	0.1
Brachythecium oedipodium **(Mitt.) Jaeg. & Sauerb.**										5		
Brachythecium spp.								5				
Dicranum fuscescens **Sm.**									0.1			0.1
Hylocomium splendens **(Hedw.) B.S.G.**												5
Lycopodium annotinum **L.**					0.1	0.1		1				
Marchantia polymorpha L.		1										
Mnium spp.								5				1
Plagiomnium drummondii **(Bruch & Schimp.) Kop.**					5							
Plagiomnium insigne **(Mitt.) Kop.**							0.1				5	
Plagiomnium spp.				25		20			3			
Pleurozium schreberi **(Brid.) Mitt.**					10	5		5	5		5	30
Polytrichum juniperinum **Hedw.**	15	20	70									0.1
Ptilium crista-castrensis **(Hedw.)**								8	20			30
Rhytidiadelphus triquetrus **(Hedw.) Warnst.**									3			3
Rhizomnium glabrescens **(Kindb.) Kop.**										5		

(1) authorities based on: Brayshaw, 1996; Douglas *et al.*, 1989; Douglas *et al.*, 1990; Douglas *et al.*, 1991; Douglas *et al.*, 1994; Hitchcock and Cronquist, 1973; Schofield, 1992; Vitt *et al.*, 1988.

Chapter Three - REVIEW OF LITERATURE

This chapter presents a review of current knowledge and information pertinent to the work conducted in this thesis. The first three sections provide a brief background behind the classification of the study pedons. The general rationale behind soil classification and the different systems used are followed by more specific information currently available about the soils of the McGregor Model Forest. The remainder of this chapter focuses on the role of fire on soils and soil nutrient cycling. Fire history information for the study area has also been provided.

3.1 Classifying Soils

Classification of the selected pedons allows for the systematic recollection and dissemination of knowledge of the soils being studied in an organized manner which may be communicated to others discussing soils (Agriculture Canada Expert Committee on Soil Survey, 1987). The historical record of attempts at differentiating between soils has been traced back over 4000 years with the early work of the Chinese (Steila and Pond, 1989). In their treatise, Baldwin *et al.* (1938) provided the essence of soil classification during its early development, "Man has a passion for classifying everything. There is a reason for this; the world is so complex that we could not understand it at all unless we classified like things together. Just as plants, insects, birds, minerals, and thousands of other things are classified, so are soils."

3.2 Taxonomic Systems of Classification

Taxonomic systems are based on the natural characteristics of whatever is being classified. With soils, these properties may include: texture, colour, structure and aggregation, mineralogy, soil temperature and moisture (and how these properties change throughout the year), cation exchange capacity and exchangeable cations, base saturation, site drainage, pH, as well as other properties which may be distinctive to different locations (Agriculture Canada Expert Committee on Soil Survey, 1987; Fanning and Fanning, 1989; Soil Survey Staff, 1994). The two systems used in this thesis were the *Canadian System of Soil Classification, Second Edition* (Agriculture Canada Expert Committee on Soil Survey, 1987) and the United States Department of Agriculture's (USDA) *Keys to Soil Taxonomy, Sixth Edition* (Soil Survey Staff, 1994).

3.2.1 Canadian System of Soil Classification

Soil surveys have been carried out in Canada since 1914. Since that time, several changes and refinements have occurred to the ways in which soil classifications are conducted. The Canadian System of Soil Classification (Canadian System) is currently being used by Canadian pedologists and others describing soils in Canada. The Agriculture Canada Expert Committee on Soil Survey (1987) listed six attributes which they felt were the basis upon which the Canadian System was developed:

1. It provides taxa for all known soils in Canada.
2. It involves a hierarchical organization of several categories to permit the consideration of soils at various levels of generality. Classes at high categorical levels reflect, to the extent possible, broad differences in soil genesis.
3. The taxa are defined specifically so as to convey the same meaning to all users.
4. The taxa are concepts based upon generalizations of properties of real bodies of soils rather than idealized concepts of the kinds of soils that would result from the action of presumed genetic processes.
5. Differences among the taxa are based upon soil properties that can be observed and measured objectively in the field or in the laboratory.
6. It is possible to modify the system on the basis of new information and concepts without destroying the overall framework.

The hierarchical approach used by the Canadian System breaks into five categorical levels: order, great group, subgroup, family and series. Table 3.1 provides a breakdown of the differentiating criteria of each of these levels.

Table 3.1 Defining taxa for the various categorical levels within the Canadian System of Soil Classification.

Categorical Level	Differentiating Criteria
Order	* nature of the soil environment * effects of the dominant soil-forming processes
Great Group	* properties that reflect differences in the strengths of the dominant processes
Subgroup	* type or arrangement of the horizons
Family	* parent material characteristics
Series	* detailed features of the pedon

3.2.2 USDA Soil Taxonomy

Similar to the Canadian System, the USDA Keys to Soil Taxonomy (Soil Taxonomy) uses a hierarchical approach to classifying soils. The major differences are the inclusion of the Cryosolic, Gleysolic and Solonetzic orders within the Canadian System and the incorporation of the suborder category in Soil Taxonomy (Agriculture Canada Expert Committee on Soil Survey, 1987; Soil Survey Staff, 1994). While Soil Taxonomy has been created with a bias towards soil genesis, an agricultural emphasis also has been stressed (Fanning and Fanning, 1989). Soil Taxonomy was devised with 10 soil orders breaking down into 47 suborders, 241 great groups and 1500 subgroups. Further subdivision may be made to the family and soil series levels. Since this system was devised to accommodate all types of soils, it has become widely used by those studying soils in countries which do not have their own soil classification systems (Buol *et al.,* 1989).

3.3 Soils of the McGregor Model Forest

A soil association is a sequence of soil series of similar age which were developed upon similar parent material under similar climatic conditions (Agriculture Canada Expert Committee on Soil Survey, 1987). The McGregor Model Forest landscape is composed of 27 soil series, including: Averil, Bearpaw Ridge, Bednesti, Bowron, Captain Creek, Chief, Cobb, Deserters, Dezaiko, Dome Creek, Dominion, Fontoniko, Fraser, Giscome, Gunniza, Hah Creek, McGregor, Merrick, Moxley, Paxton, Pineview, Ramsey, Rockland, Seebach, Spakwaniko, Stellako and Torpy River (Dawson, 1989; Driscoll, 1996; Lord, 1984; Ministry of Forests, 1977; Watt, 1980). Table 3.2 summarizes the major properties of the soil series found within the McGregor Model Forest.

3.4 Ecological Role of Fire

Fire has played an integral role in nutrient cycling and stand replacement in Canada since the Miocene (7 Ma B.P.) (Weber and Taylor 1992). In 1973, it was estimated that 0.3% of the country's forest area burns every year (Rowe and Scotter, 1973), that figure has been revised to 0.6% of Canada's forests (Simard, 1997). In fact, it also has been estimated that double this amount, or 1.0 - 1.3% of Canada's forested land would burn annually if not for fire suppression activities (Simard, 1997). Fire continues to be a dominant factor in the Sub-Boreal Spruce (SBS) biogeoclimatic zone of British Columbia. Factors such as fire intensity, fire temperature, vegetation types, amounts and types of fuels, topography, micro- and meso-climates all play different

Table 3.2 Soil Series of the McGregor Model Forest

Soil Series	Physiographic Subdivision	Dominant Soil Type	Common Texture	Common Drainage
Averil	Fraser Plateau, McGregor Plateau	Orthic Humo-Ferric Podzol	sandy loam	moderately well to well
Bearpaw Ridge	Fraser Plateau, McGregor Plateau, Rocky Mountains	Orthic Humo-Ferric Podzol	sandy loam	well
Bednesti	Fraser Basin, Nechako Plain	Brunisolic Gray Luvisol	silt loam	moderately well
Bowron	Fraser Basin, McGregor Plateau	Brunisolic Gray Luvisol	silt loam	moderately well
Captain Creek	Quesnel Highland, McGregor Plateau, Rocky Mountains	Orthic Humo-Ferric Podzol	sandy loam	moderately well
Chief	Fraser Plateau	Typic Mesisol	fibric	very poorly
Cobb	Fraser Plateau	Orthic Humo-Ferric Podzol	sandy loam	well
Deserters	Fraser Plateau	Brunisolic Gray Luvisol	loam	moderately well
Dezaiko	Fraser Plateau, McGregor Plateau, Rocky Mountains	Orthic Humo-Ferric Podzol	sandy loam	moderately well to well
Dome Creek	Rocky Mountain Trench, McGregor Plateau	Eluviated Dystric Brunisol		rapidly to well
Dominion	Fraser Plateau, Fraser Basin, McGregor Plateau	Luvisolic Humo-Ferric Podzol	loam	moderately well
Fontoniko	Fraser Plateau, Quesnel Highland, McGregor Plateau	Eluviated Dystric Brunisol	sandy loam	well to rapidly
Fraser	Nechako Plain	Orthic Gray Luvisol	silt loam	moderately well
Giscome	Fraser Basin	Orthic Dystric Brunisol	loamy sand	rapidly
Gunniza	Rocky Mountain Trench, Fraser Basin	Orthic Humo-Ferric Podzol	loamy sand	rapidly

Hah Creek	McGregor Plateau	Sombric Humo-Ferric Podzol		moderately well to imperfectly
McGregor	Rocky Mountain Trench, Fraser Basin, McGregor Plateau	Gleyed Regosol	loam	imperfectly
Merrick		Orthic Humo-Ferric Podzol.	sandy loam	well
Moxley	Rocky Mountain Trench, Fraser Basin, McGregor Plateau	Mesic Fibrisol	fibric	very poorly
Paxton	McGregor Plateau, Rocky Mountains	Orthic Humo-Ferric Podzol	loam	well
Pineview	Fraser Basin	Gleyed Gray Luvisol	heavy clay	imperfectly
Ramsey	Fraser Plateau	Orthic Humo-Ferric Podzol	loamy sand	rapidly
Seebach	Fraser Plateau	Orthic Humo-Ferric Podzol	loamy sand	well
Spakwaniko	Quesnel Highland, Cariboo Mountains	Orthic Humic Gleysol	sandy loam	poorly
Stellako	Rocky Mountain Trench	Gleyed Regosol	sandy loam	poorly to imperfectly
Torpy River	Fraser Plateau	Orthic Humo-Ferric Podzol	sandy loam	moderately well

rapidly drained = soil holds little moisture after rain, well drained = no excess moisture for most of the year, moderately well drained = excess moisture for a short but significant period of the year, imperfectly drained = soil remains wet in subsurface horizons for a moderately long period of the year, poorly drained = excess moisture throughout soil for a large part of the year, very poorly drained = free water remains at or within 30 cm of the surface most of the year

from Dawson, 1989; Driscoll, 1996; Lord, 1984; Ministry of Forests, 1977; Watt, 1980

roles in determining how the fires will affect nutrient losses and nutrient cycling as well as the soils physical properties. Much of the floral and faunal diversity in Canada's boreal forests can be attributed to lightning and human-caused fires which affect ecosystem composition, soil chemical properties and temperature (Rowe and Scotter, 1973). In examining the fire history of the Bowron Lake Park near Prince George, Parminter (1993) discussed the historical role fire has played, "Natural fire has served to maintain a variety of forest age classes on the landscape, with each burned area containing a tree species mixture which reflects the site's ecological characteristics, vegetative composition at the time of the fire and post-fire conditions."

3.5 Fire Causes and Patterns

Forest fires may be caused by lightning, volcanic eruptions, sparks from falling rocks and even spontaneous combustion in marshy areas, as well as by human activities (Sousa, 1984). Lightning-caused fire frequency in the southern Canadian Rockies has been characterized by few, infrequent large fires determining the forest age mosaic, i.e., 2% of the lightning fires caused 95% of the total area burned (Johnson and Gutsell, 1994; Johnson and Wowchuk, 1993; Parminter, 1990). For all of Canada's forests, lightning is reported to cause 42% of all fires leading to 85% of the area burned (Simard, 1997).

Fire occurrences have been traced along shifting climatic regimes since the end of the last glaciation. Pollen and charcoal records indicate that fire patterns follow the changes in vegetation distribution which resulted from changes in climate (Edlund and Byrne, 1990).

Examination of fire frequency records of three national parks and a forest reserve within the southern Canadian Rockies indicated a fire return interval of approximately 100 years over the 20,500 km^2 area examined (Johnson and Wowchuk, 1993). Their report shows periods in which weather patterns develop into high-pressure ridges within the troposphere stalling in the Rockies and preventing moist low-pressure systems from entering the regions. Since these blocking events are on scales of 100 km - 1000 km, this leads to a large scale drying of the soil and vegetation and a condition conducive to large fires.

Fire frequency patterns have changed considerably since the arrival of European settlers to western North America. Fire exclusion together with grazing and timber harvesting have all led to changes in ecosystem structures, landscape patterns and disturbance regimes that are different from the patterns that have evolved with the indigenous biota (Covington *et al.*, 1994). However, these patterns vary considerably by ecosystem. For example, ponderosa pine communities in the American Inland West have been determined to have had historic low intensity fires at return intervals from as little as 5-10 years to as much as 20-30 years, maintaining comparatively open, fuel-free stands, compared to high intensity and stand replacing fires at intervals as long as 200+ years for higher elevation lodgepole pine/subalpine fir/Engelmann spruce forests (Mutch, 1994; Steele, 1994). The record of all the fires which occurred in Canada between 1961 and 1967 showed that 85% of the events were smaller than or equal to 4 ha (Rowe and Scotter, 1973) and another study shows the average fire size being 315 ha (Simard, 1997). In the case of fire exclusion, a different plant succession can change the species composition and density beyond the historic range for these communities. Outbreaks of insects and disease may become more frequent or damaging (Steele, 1994).

It should be stressed that fire behaviour and ecosystem reactions to fire vary considerably by ecosystem and attempts to link different systems should be made with great caution (Ahlgren, 1974).

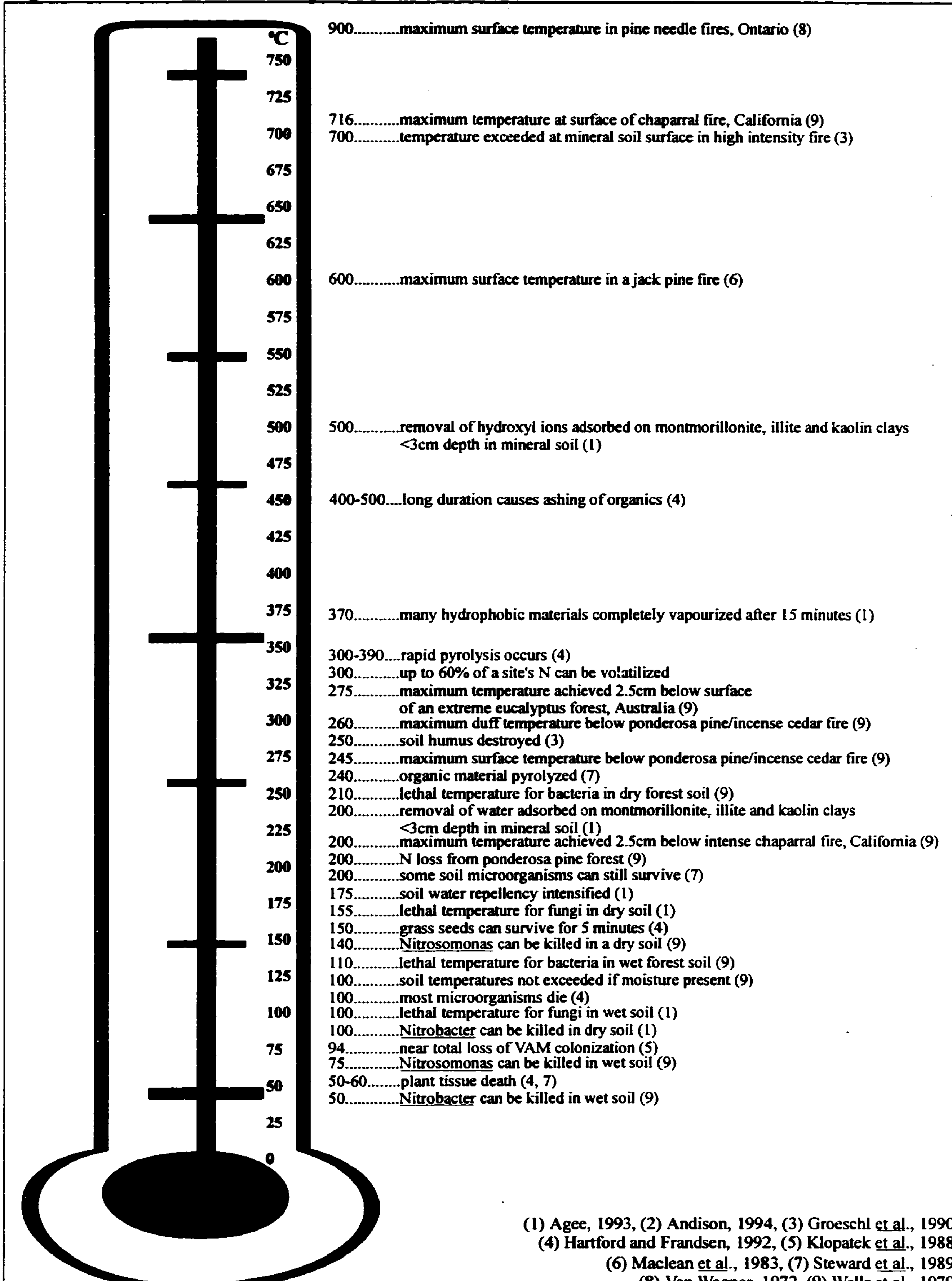
3.6 Fire Types and Heat Movement in Forest Floors and Soils

The three main types of fire are: ground fires, surface fires, and crown fires (Figure 3.1). Each of these types has different properties and characteristics and, thus, will have different effects on the forests they burn. The severity of each of these types of fire partly may be described by the temperatures reached within the forest floor and the duration of the heating experienced by the vegetation, in the forest floor and underlying mineral soil (Hartford and Frandsen, 1992). However, the degree to which a soil can be heated during any type of fire is dependent on the type of fuel, fire intensity and duration, nature of the litter layer and soil properties (such as the level of organic matter, moisture content) and is, therefore, highly variable (Wells *et al.,* 1979). When water is present in the soil, the temperature of the soil will not exceed 100°C until the water has evaporated or leached to lower soil layers (Wells *et al.,* 1979). Figure 3.2 demonstrates how temperature changes affect different selected soil constituents or properties.

Figure 3.1 Schematic illustration of ground, surface and crown fire locations

Ground fires (or subsurface fires) burn duff, roots, buried wood and peat below the litter layer of the forest floor. They normally support smouldering or glowing combustion as duff slowly is pyrolysed

Figure 3.2 Effects of temperature on selected soil constituents.



to char (Hartford and Frandsen, 1992; Merrill and Alexander, 1987). However, moisture and the presence of inorganics can stop the smouldering combustion and extinguish ground fires (Hartford and Frandsen, 1992). Sandberg (1980) showed that duff with a moisture content greater than 120% will not burn regardless of the amount of surface fuels, while Hawkes (1993) found that peat material would smoulder in conditions of over 200% moisture content when an external heat source (like that from a surface fire) was applied.

Surface fires are fires in which the materials above the duff layer act as the fuel source of the fire (Merrill and Alexander, 1987). Crown fires occur when the standing and supported forest materials which are not in direct contact with the ground (foliage, twigs, branches, cones) are the primary fuel source for burning (Merrill and Alexander, 1987). Both crown and surface fires burn by flaming combustion as pyrolysing fuel releases volatile gases that mix with air and are heated to ignition (Hartford and Frandsen, 1992). All three fire types can occur in one forest fire and are usually not separate entities.

The direction of the prevalent wind in relation to the aspect of the slope upon which a fire is burning is important in determining fire behaviour. Wind tilts flames of a fire forward which results in a preheating of the fuels ahead of the fire front. The heating of the fuels leads to increased spreading rates of the fire and increased fire intensity. The slope reacts in much the same manner by tilting fuels toward or away from the flaming front (McAlpine *et al.*, 1991).

Generally the fine fuels (≤ 7 cm in diameter) are the first to ignite during a fire. They may act as kindling to the large fuels (> 7 cm in diameter) and combust quickly because of their low moisture content and high surface-to-volume ratio (Little, 1990). Moist duff can provide considerable protection from heating to the mineral soils below (Hartford and Frandsen, 1992). The presence of water in duff, or within the mineral soil itself, changes the heat capacity and thermal conductivity of the substrate (Frandsen and Ryan, 1986). Since water absorbs 4.18 joules for each degree Celsius increase in temperature, following evaporation, less energy remains for heat transfer than would be experienced in dry duff or a dry mineral soil (Agee, 1993). In addition, moisture within the duff layer can act as a prevention to ignition of ground fires (Hungerford *et al.*, 1993). However, while moisture will decrease the maximum temperature of the heat being transferred, the wet soil is still a better conductor of the remaining heat and may transfer it to greater depths than might be experienced in dry soils (Agee, 1993).

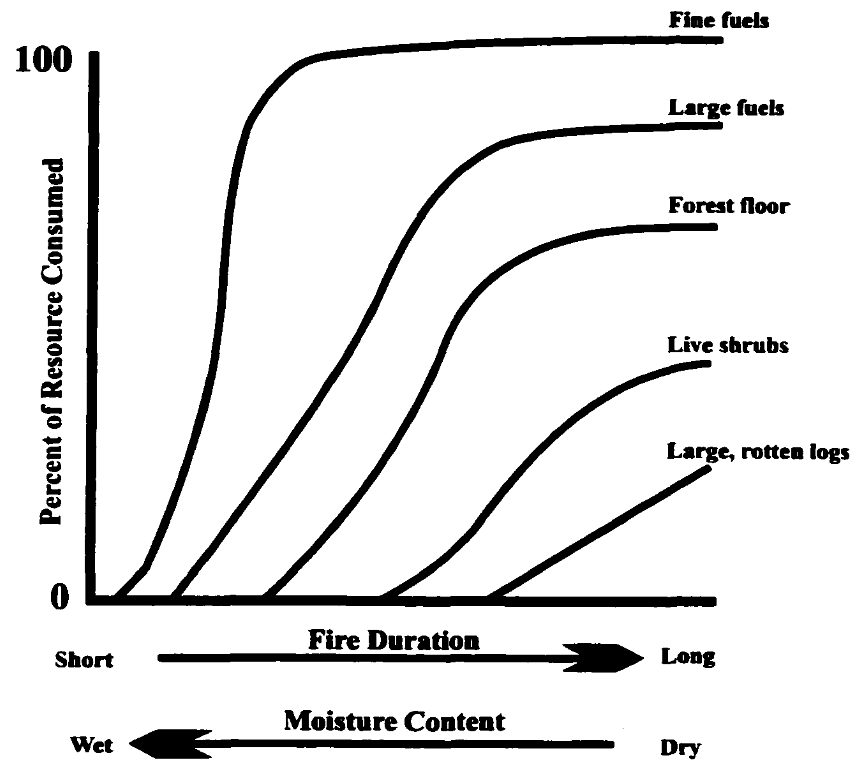
Hungerford *et al.* (1993) predicted that moisture levels in duff adjacent to a burning zone may affect the progression of the fire. It is possible for moisture to be drawn in to replace moisture lost by the advance of the fire as well as the possibility for moisture to be pushed away from the burning zone. However, the condition of these fuels depends, in part, on the weather. Dead fuels will reflect moisture regimes of both past and recent weather, whereas live fuels will reflect a more seasonal regime (Rowe and Scotter, 1973).

The materials composing the duff layer acts as a factor in determining how deep a fire will burn in this layer. In their examination of duff consumption models, Reinhardt *et al.* (1991) determined that, under specific conditions, duff derived of short needled litter were more readily consumed than duff from longer needled forests.

Figure 3.3 provides a generalized graph of the relationships between fire duration, fuel moisture content and the percent of the fuel consumed. Of note are the times following fire initiation and the moisture content versus the type of fuel. The fine fuels ($\leq$ 7 cm in diameter) are the first to ignite and then the heat generated from their flaming acts as kindling for the remainder of the fuels.

In their study within the moist, cool SBS subzone in central British Columbia, Taylor *et al.*

Figure 3.3 Relationship between fire duration and moisture content to the amount of resources consumed.



Note: fine fuels ≤ 7 cm diameter, large fuels > 7 cm diameter.

from Little, 1990

(1991) indicated that the observed depth and duration of 60°C temperatures were related to plant tissue death (also see Hartford and Frandsen, 1992; Steward *et al.*, 1989) and were linked with the amount of slash and forest floor consumed during a fire event. Their study showed that the maximum temperatures reached in the spray and burn and the broadcast burn treatments were sufficient to kill above-ground plants in most of their locations and below-ground plants in 20% of their locations to a depth of 3 cm and 3% to a depth of 7 cm. Within the same biogeoclimatic zone, Blackwell *et al.* (1992) determined that consumed biomass from a fire increased with preburn biomass levels regardless of the moisture content of the fuel because the slash had been placed in windrows for burning.

3.7 Fire Patterns within the McGregor Model Forest

Over the forty year period from 1951 to 1991, the B.C. Ministry of Forests, Protection Branch recorded 403 fires occurring within and immediately surrounding the McGregor Model Forest in Central British Columbia (Taylor, 1995). These fires burned almost 2000 ha within four different biogeoclimatic zones and six subzones. Table 3.3 shows the numbers of fires per subzone and the total area burned.

Table 3.3 Fires within the McGregor Model Forest between 1951 and 1991 according to biogeoclimatic subzone.

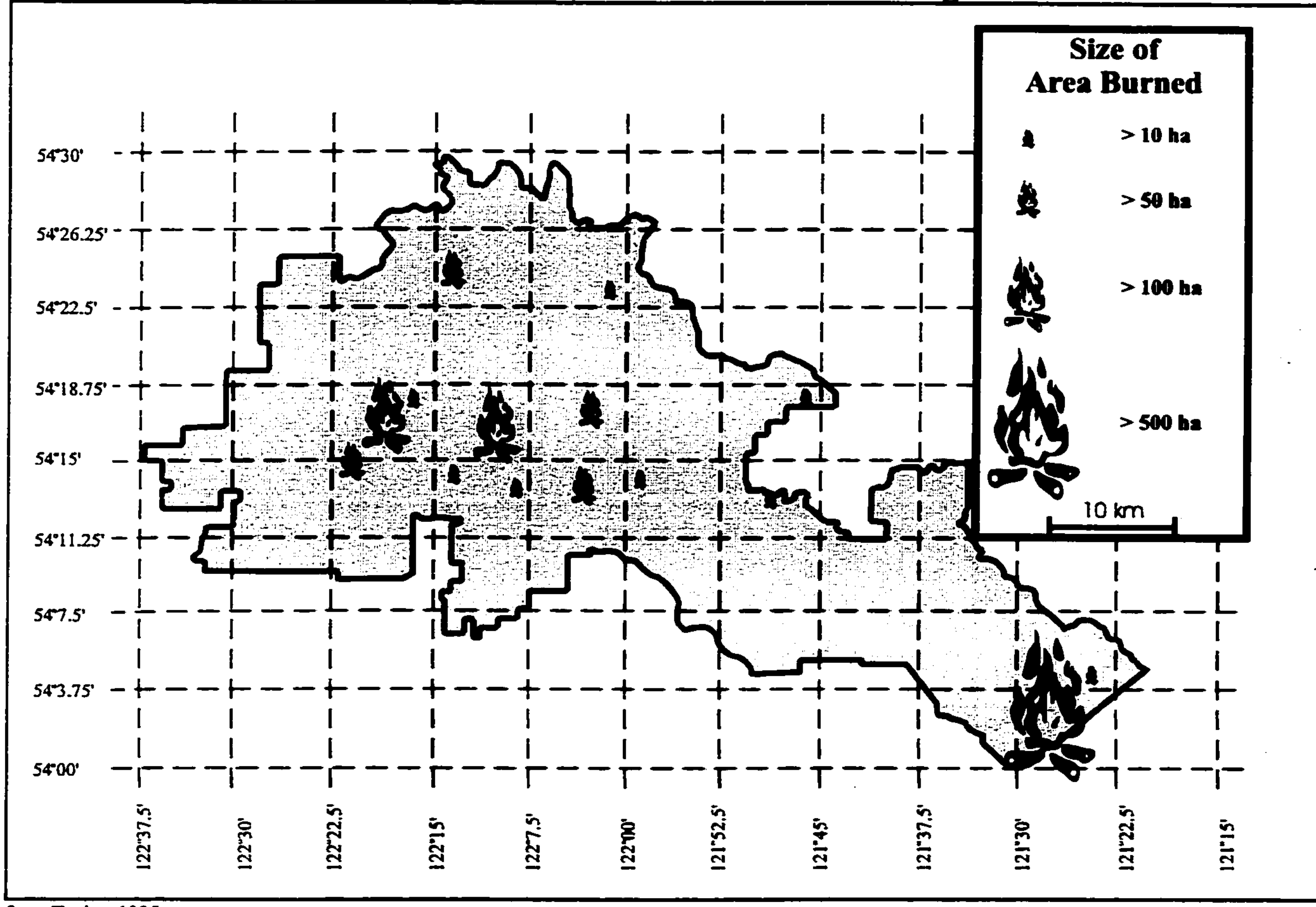
BGC Zone	# of fires	% of fires	Total (ha)	% of total burned area
SBSvk	150	37.2	974.3	49.2
SBSwk	197	48.9	979.5	49.5
SBSmk	19	4.72	19.9	1.00
ESSFwk	20	4.96	4.6	0.23
ICHvk	12	2.98	2.1	0.11
Tundra	4	0.99	0.2	0.01
Unclass	1	0.25	0.1	0.01
Total	403	100	1980.7	100

from Taylor, 1995 (vk = very wet, cool subzone; wk = wet, cool subzone; mk = moist, cool subzone; ESSF = Engelmann Spruce-Subalpine Fire zone; ICH = Interior Cedar Hemlock zone)

Of the 366 fires recorded within the SBS biogeoclimatic zone of the McGregor Model Forest between 1951 and 1991, only 13 fires burned areas greater than 10 ha, yet these fires represented more than 97% of the total area burned (Taylor, 1995). Figure 3.4 shows the locations of all the fires within the McGregor Model Forest which were greater than 10 ha.

Six major causes of forest fires occurring within the McGregor Model Forest have been recognized by the BC Ministry of Forests, Protection Branch: (1) lightning; (2) recreational activities; (3) railroad activities; (4) logging activities; (5) other industrial activities, and; (6) land clearing and brush

Figure 3.4 **1951-1991 fires greater than 10 ha within the McGregor Model Forest.**



from Taylor, 1995

burning (B. Hawkes, personal communication, 1996; Taylor, 1995). Table 3.2 provides a breakdown of the listed causes of the fires recorded within the McGregor Model Forest. Again, the dominance of lightning-caused fires is demonstrated as they are responsible for over 93% of the total number of fires accounting for almost 69% of the total burned area.

3.7.1 The SBS Subzones within the McGregor Model Forest

Over 90% of the fires within the McGregor Model Forest were within the SBS biogeoclimatic zone (the largest zone within the McGregor Model Forest) encompassing over 99% of the total area

Table 3.4 Causes of fires within the McGregor Model Forest between 1951 and 1991.

Cause of fire	# of fires	% of fires	Total (ha)	% of total area burned
Lightning	376	93.30	1358.6	68.6
Recreation	2	0.50	0.2	0.01
Railroads	2	0.50	3.6	0.18
Logging	16	3.97	533.6	26.9
Other industrial	1	0.25	81.6	4.12
Land clearing/ brush burning	1	0.25	0.1	0.005
Unknown	5	1.24	3	0.15
Total	403	100	1980.7	100

from Taylor 1995

burned. Of the remaining subzones, only the ESSF and ICH account for more than 0.1% of the total burned area. The tundra and one unclassified zone combine for only five fires burning an area of less than 0.02 ha and will not be discussed further.

Surface and crown fires predominate the SBS with mean fire return intervals between 100 - 150 years on average burning 50 - 500 ha (Parminter, 1992). Tables 3.5, 3.6 and 3.7 detail the breakdown of the fire record for the different SBS subzones within the MMF. Of particular interest are the contrast between the high frequency of fires burning small areas compared to the few very large fires. In each case, the number of fires over 5 ha account for less than five percent of the total number of fires in the subzone while accounting for the majority of the area burned. This may be considered an indication of the fire history of this area with many small fires being highlighted by very few stand replacing fires. However, it should be noted that the fires recorded belong to a period of fire suppression and may not be representative of fire prehistory within the area. This trend is also prevalent in each of the other biogeoclimatic zones occurring within the McGregor Model Forest.

Table 3.5 Fires in the SBSvk biogeoclimatic subzone within the McGregor Model Forest.

Size (ha)	# of fires	% of fires	Total (ha)	% of total burned area
0	20	13.33	0	0.00
0.1	109	72.67	10.9	1.12
0.2	6	4.00	1.2	0.12
0.3	1	0.67	0.3	0.03
0.6	1	0.67	0.6	0.06
0.6	1	0.67	0.6	0.06
0.8	1	0.67	0.8	0.08
1	1	0.67	1	0.10
1.8	1	0.67	1.8	0.18
3.5	1	0.67	3.5	0.36
4	1	0.67	4	0.41
10.6	1	0.67	10.6	1.09
10.9	1	0.67	10.9	1.12
22	1	0.67	22	2.26
35	1	0.67	35	3.59
68	1	0.67	68	6.98
161	1	0.67	161	16.52
642.1	1	0.67	642.1	65.90
Total	150	100	974.3	100

from Taylor, 1995

Table 3.6 Fires in the SBSwk biogeoclimatic subzone within the McGregor Model Forest.

Size (ha)	# of fires	% of fires	Total (ha)	% of total burned area
0	24	12.18	0	0.00
0.1	132	67.01	13.2	1.35
0.2	11	5.58	2.2	0.22
0.3	3	1.52	0.9	0.09
0.4	2	1.02	0.8	0.08
0.5	1	0.51	0.5	0.05
0.7	1	0.51	0.7	0.07
0.8	1	0.51	0.8	0.08
1	2	1.02	2	0.20
1.2	1	0.51	1.2	0.12
1.5	1	0.51	1.5	0.15
1.7	1	0.51	1.7	0.17
2	3	1.52	6	0.61
4	1	0.51	4	0.41
4.1	1	0.51	4.1	0.42
4.8	1	0.51	4.8	0.49
5.2	1	0.51	5.2	0.53
5.6	1	0.51	5.6	0.57
6	1	0.51	6	0.61
13.3	1	0.51	13.3	1.36
16.1	1	0.51	16.1	1.64
16.9	1	0.51	16.9	1.73
19.4	1	0.51	19.4	1.98
58	1	0.51	58	5.92
81.6	1	0.51	81.6	8.33
322	1	0.51	322	32.87
391	1	0.51	391	39.92
Total	197	100	979.5	100.00

from Taylor, 1995

Table 3.7 Fires in the SBSmk biogeoclimatic subzone within the McGregor Model Forest.

Size (ha)	# of fires	% of fires	Total (ha)	% of total burned area
0	2	10.5	0	0.00
0.1	12	63.2	1.2	6.03
0.2	2	10.5	0.4	2.01
0.8	1	5.26	0.8	4.02
6.2	1	5.26	6.2	31.2
11.3	1	5.26	11.3	56.8
Total	19	100	19.9	100

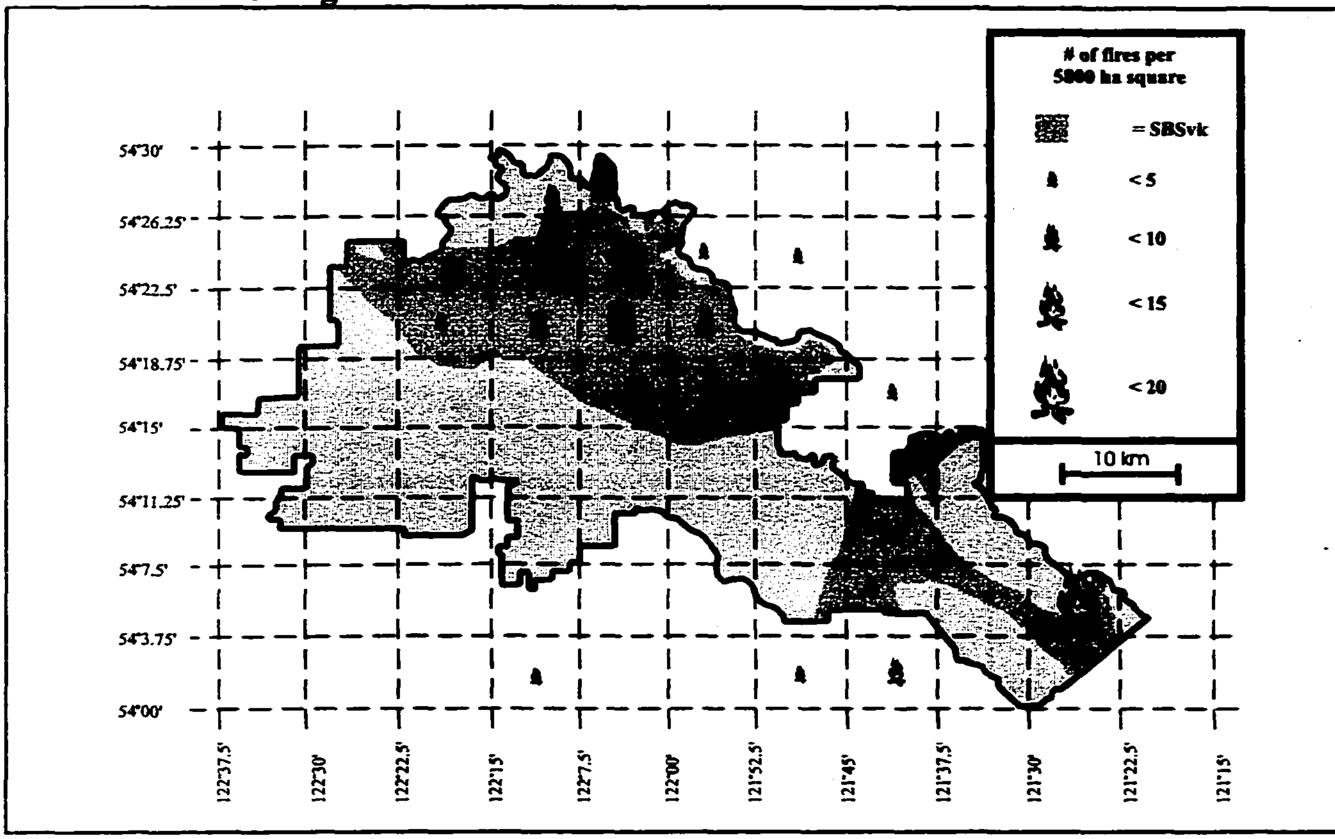
from Taylor, 1995

Figures 3.5, 3.6 and 3.7 show the spatial distributions of the recorded fires within the different subzones of the SBS. Each of the quadrats represents an area of approximately 5800 ha and was delineated by latitude and longitude.

3.8 Fire and Soil Nutrients

Fire is the main force involved in nutrient recycling in the forests of the Rocky Mountains. It provides the opportunity for nutrients which are immobilized in biomass and soil to be recycled into the soil through the burning of organic matter (Lathrop, Jr., 1994; Steele, 1994). This is important as low rates of decomposition in northern boreal spruce forests tend to tie up the nutrients in the forest floor making them largely unavailable to plants. However, forest fires can lead to the loss of nutrients through volatilization during pyrolysis or combustion, loss in the particulate matter of smoke, transfer of mineral elements to the ash layer, leaching and the heating of biomass and upper soil layers (sometimes to temperatures above lethal levels for microbial survival) as well as being blown away with ash residues following the fire (Feller, 1982; Grier, 1975; MacLean *et al.*, 1983).

Figure 3.5 1951 - 1991 fires in the SBSvk within and immediately surrounding the McGregor Model Forest.

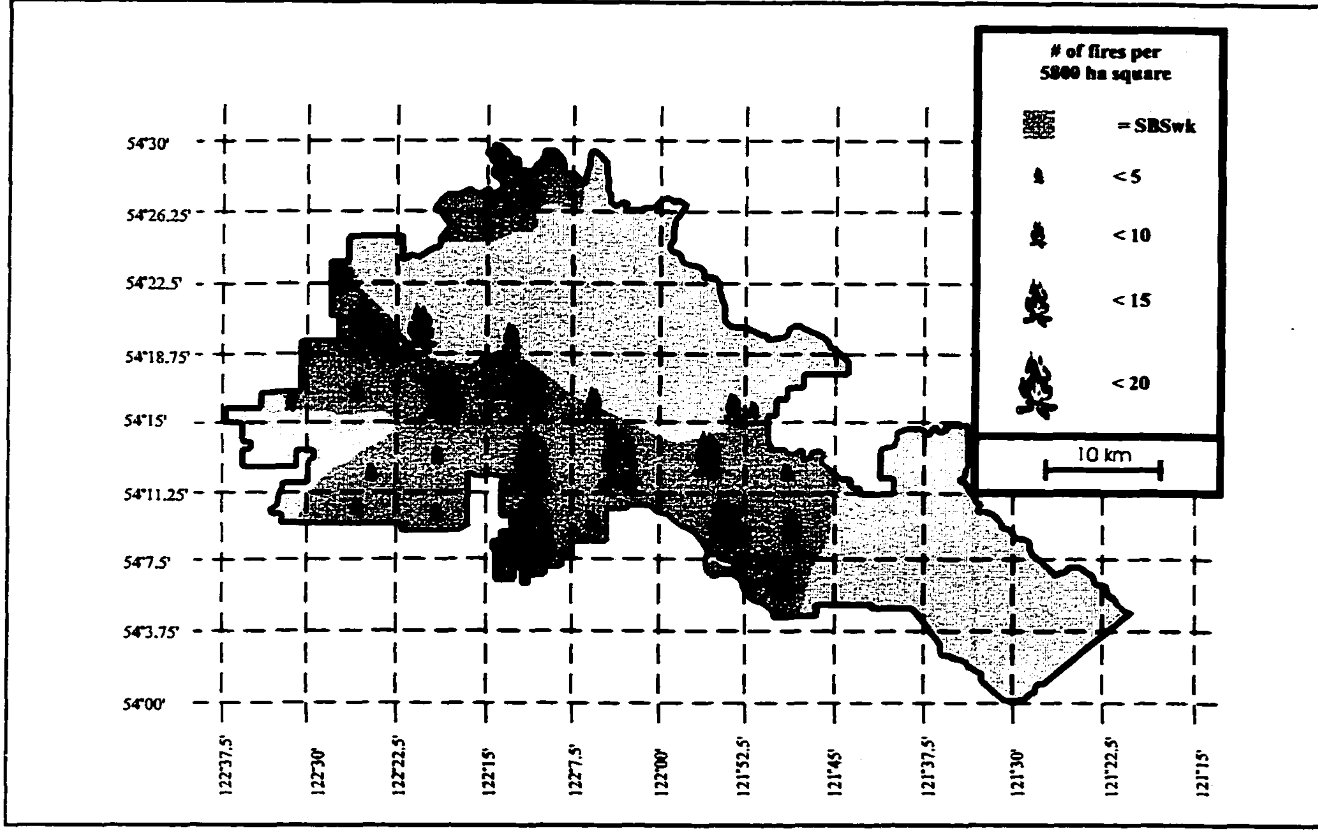


Forest fires also lead to a redistribution of nutrients within ecosystems. Figure 3.8 shows the direct and indirect affects of fire on nutrient cycling in northern ecosystems. However, MacLean *et al.* (1983) note that the magnitudes of the redistributions have not been well quantified; although the direction of the movement is well understood.

3.8.1 Post-Fire Nutrient Cycling

Burning of forests has been shown to increase the short-term availability of nutrients to the soil, but also show the adverse effects of nutrient loss over the longer term (Hawkes *et al.*, 1990)with variations between the different nutrients. Figure 3.9 demonstrates the loss of selected

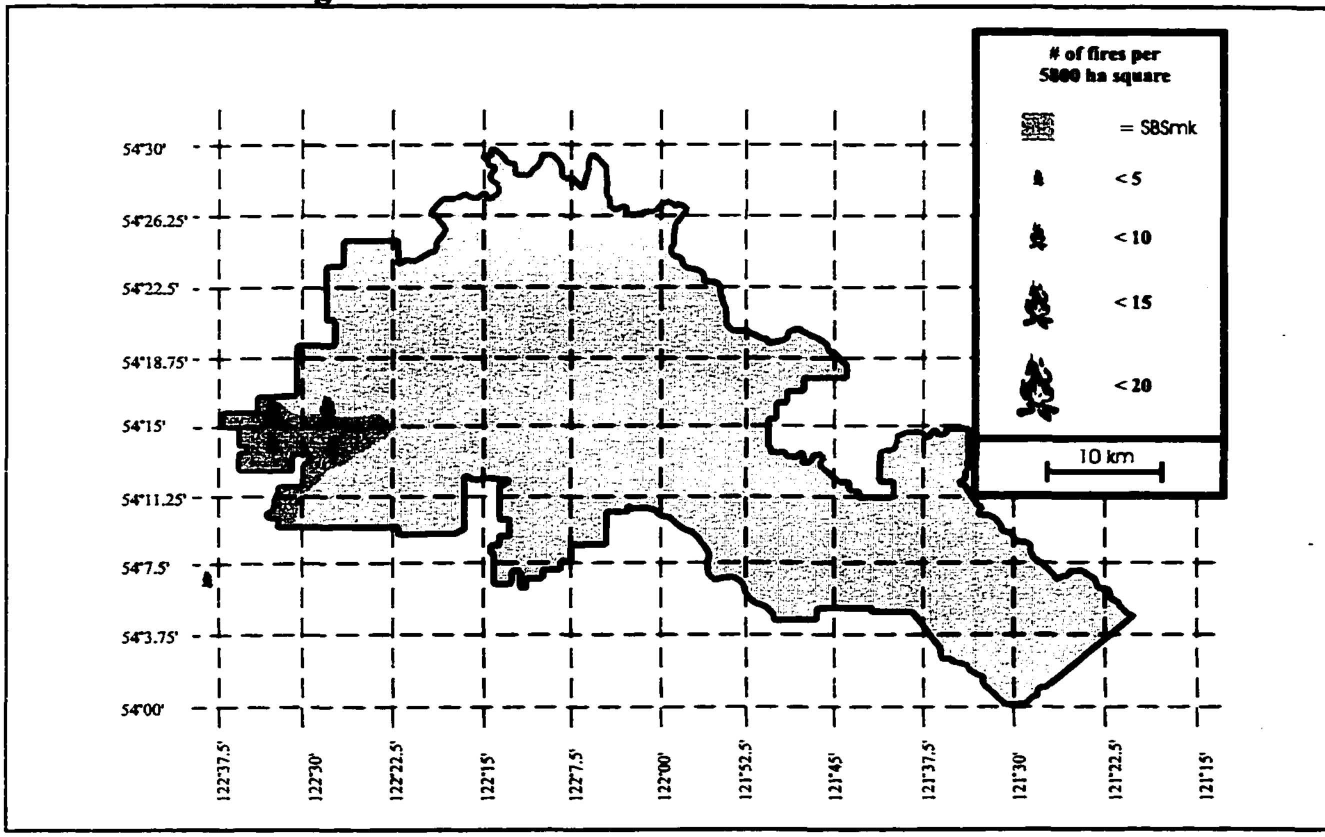
Figure 3.6 1951 - 1991 fires in the SBSwk within and immediately surrounding the McGregor Model Forest.



nutrients from the soil through volatilization as a function of increasing temperature. The potassium and sodium, however, may be released from plant tissues leading to increased cation concentrations in the soil (Helvey *et al.,* 1976).

Feller (1989) stated that the best method to measure nutrient losses to the atmosphere from forest fires was to determine the depth-of-burn of the forest floor. In the Coastal Western Hemlock biogeoclimatic zone, Feller (1989) found that total nitrogen levels in the forest floor were reduced by 60-85%. Several other nutrients experienced heavy percentage losses from burning (phosphorus 30-75%, potassium 20-60%, magnesium 60-85%, and calcium 20-50%) though nitrogen losses were the greatest (by weight) ranging from as low as 10 kg/ha to as much as 1000 kg/ha in areas

Figure 3.7 1951 - 1991 fires in the SBSmk within and immediately surrounding the McGregor Model Forest.

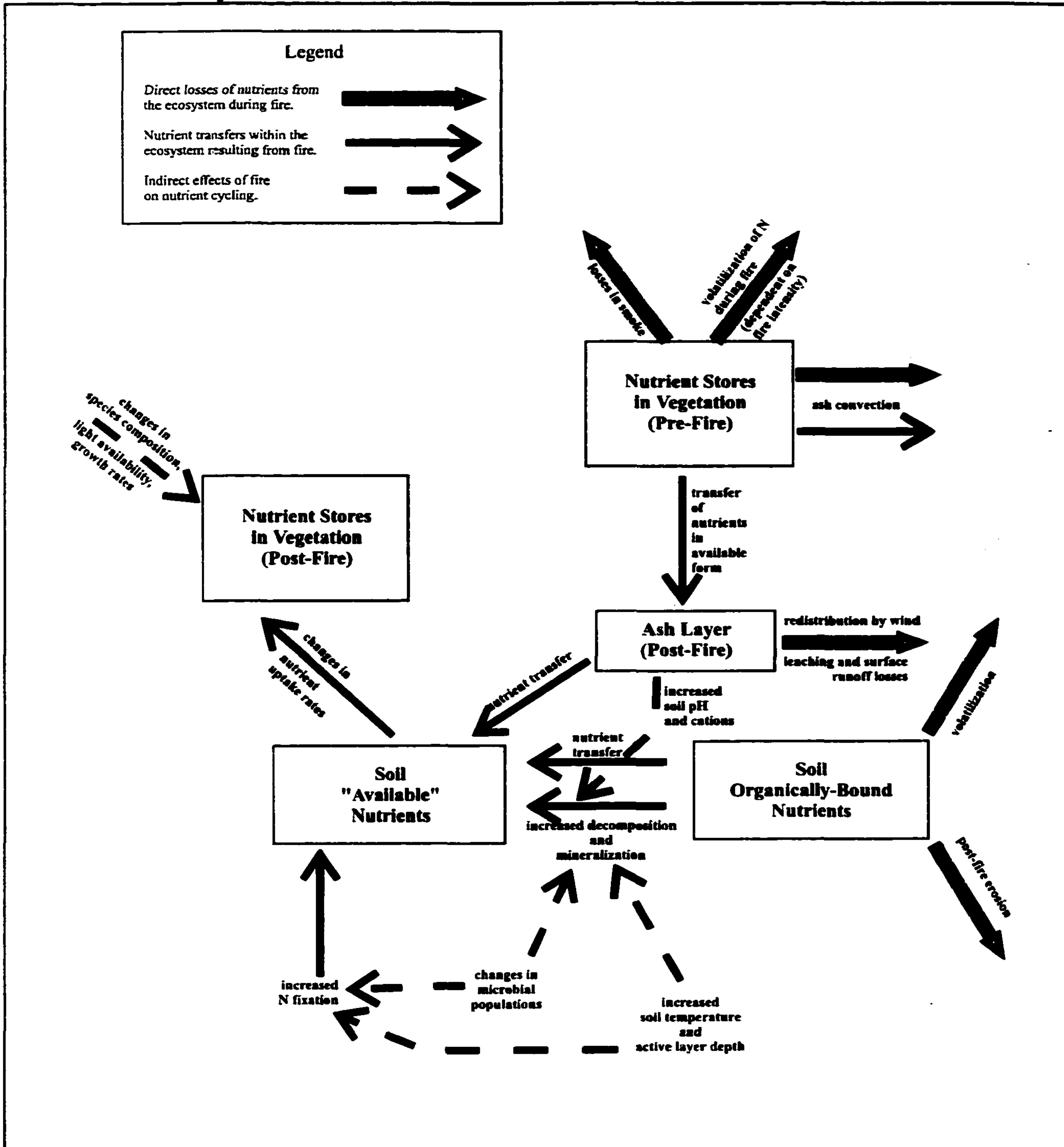


with preburn slash loads between 10 kg/m^2 and 30 kg/m^2 and depth-of-burns ranging from 0.1-6.4 cm. This is similar to maximum losses of total nitrogen of 900 kg/ha from the soil in Pacific Northwest forests (Agee, 1993).

Feller (1989) further recorded total nitrogen losses from broadcast slashburns within the Sub-Boreal Spruce biogeoclimatic zone of 551 kg/ha (depth-of-burn = 3.0 cm) and 324 kg/ha (depth-of-burn = 1.9 cm) in mesic and subhygric sites, respectively.

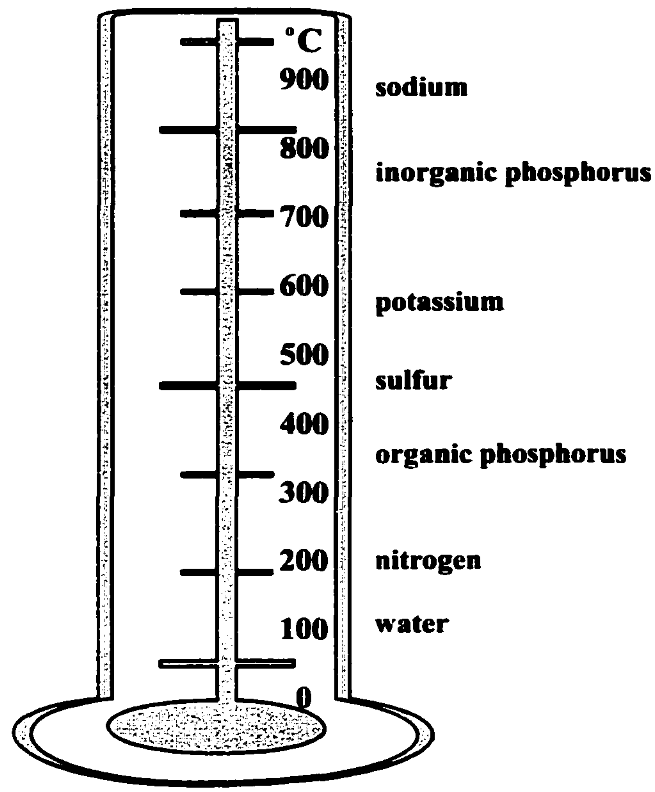
It should be noted, however, that nutrient losses from fire may be partially offset by the deposition from precipitation. Helvey *et al.* (1976) determined that as much as 1.1 kg/ha of nitrogen and 8.5 kg/ha of the four base cations (Ca, K, Mg, Na) was deposited in the annual snowfall. Their

Figure 3.8 Possible direct and indirect effects of fire on nutrient cycling in northern ecosystems.



from MacLean *et al.*, 1983

Figure 3.9 Loss of soil nutrients at various temperatures.



from Agee, 1993

study in Washington State was climatically similar to areas within the interior of British Columbia. Their watershed had an annual precipitation minimum and maximum of 203 mm and 787 mm, respectively, with an annual average of 579 mm at 915 metres above sea level (m.a.s.l.); these precipitation values are within the lower ranges of the SBS biogeoclimatic zone.

One method of determining nutrient loss from fires is to examine the levels of nutrients in streams or channels. With natural background levels determined prior to a fire event, changes in the amounts of nutrients which normally runoff or are leached to ground water may be followed (Feller and Kimmins, 1984; Helvey *et al.,* 1976; Lathrop, Jr., 1994). In their study, Helvey *et al.* (1976) followed nutrient cycling over a three year period in three Pacific Northwest watersheds following forest fires. Total nitrogen was found to rise steadily following the fire event while the base forming cations dropped in concentration due to increased runoff into streams (Table 3.8). However, Lathrop, Jr. (1994) noted that nutrient uptake by vegetation which begins to occur during vegetative succession in the months and years following the fire event eventually leads to a decrease in nutrient leaching into streams.

Table 3.8 Nutrient changes in streams following a Pacific Northwest forest fire.

Nutrient	1970 (Pre-Fire) mg/L	1971 (1 YR Post-Fire) mg/L	1972 (2 YR Post-Fire) mg/L
Total N	0.047	0.064	0.10
Ca	8.8	7.3	5.0
Mg	1.5	1.3	0.9
Na	2.9	no data	2.3
K	1.3	no data	0.9
Base Cations (Monthly Mean)	14.5	12.5	9.1

from Helvey *et al.*, 1976

Grier (1975) reported losses of a large proportion of base cations from leaching during the first snowmelt during the spring following a late August fire in the Entiat Valley of Washington State. The study found that 35% of the calcium, 78% of the magnesium, 85% of the potassium and 94% of the sodium originally in the ash layer was leached between the May - June sampling period. It was also noted that over 90% of the calcium, magnesium and potassium from the percolating water was held within the first 19 cm of the mineral soil. Conversely, in another study, Boyle (1973) noted that not all of the mineralized potassium was retained in the upper 20 cm in a Wisconsin pine plantation. This was believed to have been the result of the low cation exchange capacity of the coarse-textured soil of the area.

Helvey *et al.* (1985), in another study of nutrient loss, examined levels within transported sediments (debris torrents, suspension, bedload). In the five years following a fire event in the eastern Cascade Range of Washington, losses of nitrogen increased between 14 and 38 times the normal loss rate (total transported nitrogen increased from 0.004 kg/ha/yr to 0.16 kg/ha/yr), available phosphorus losses were 14 times higher than pre-fire levels (from 0.001 kg/ha/yr to 0.014 kg/ha/yr), losses of calcium and magnesium averaged 26 times greater, losses of sodium were increased by 25 times and potassium jumped to losses 32 times more than the pre-fire levels (combined losses of the four base cations increased from 1.98 kg/ha/yr to 54.3 kg/ha/yr).

Within the SBS zone, Taylor and Feller (1986) showed an immediate increase in available nitrogen, phosphorus, potassium, magnesium and calcium levels as well as a higher pH due to the ash deposition following a prescribed burn which had a relatively low depth-of-burn and slash consumption. However, after a period of nine months, mineralizable nitrogen and pH levels were the only two factors with levels higher than the pre-fire results. The cations had all been reduced to a level lower than pre-fire conditions. In sandy podzolic soils (as are found within the SBS zone of the McGregor Model Forest), nutrient gain may be short lived as water-soluble cations are easily leached when humus layers are removed (Rowe and Scotter, 1973).

Combustion of the duff layer leads to a reduction of organic matter and a release of cations

(Pietikainen and Fritze, 1992; Steward *et al.*, 1989). Combustion of the organic matter composing the duff layer also leads to the release of mineral substances in the form of oxides which may be turned into carbonates and hydroxides causing a decrease in the acidity of the soil (Fritze *et al.*, 1993). Andison (1994) noted that it is rare for the entire layer of organic matter to burn and that the consumption of organic matter is predicated by its moisture content and the fire intensity (specifically the residence time and downward heat pulse from the surface fire).

The level to which a fire may affect soil nutrients has been tied to the clay and humus content of the A horizon (Kelsall *et al.*, 1979). It has been hypothesized that soils having a high clay content and a "substantial" humus content in the A horizon would lose a minimal percentage of their nutrient base from burning. Conversely, soils low in clay and humus in the A horizon rely on the forest floor (L, F and H horizons) for their moisture and nutrient-holding capacity and may be subjected to more severe changes to their physical and chemical properties such as an increased bulk density, lower water-holding capacity and reduced fertility.

Following a fire in a Mediterranean-type forest in Israel, Kutiel and Naveh (1987) found an immediate flush of ammonium and nitrate which returned to pre-fire levels over a period of two to four months. Total phosphorus jumped 300% immediately after the fire due to the turning of the plants and litter into ash, but the levels returned to pre-fire levels within two months. It was believed that the reduction of nutrients following the post-burn increases were primarily due to leaching from rain. Similar findings were reported by Lewis, Jr. (1974) in a South Carolina pine forest.

In southern pine forests, Groeschl *et al.* (1990) found that low intensity fires improve the soil fertility by raising the pH and providing an influx in inorganic forms of nutrients and increasing the solubility of the nutrients. Low intensity fires can also volatilize monoterpenes and other similar compounds which inhibit bacterial growth necessary for ammonification and nitrification (Groeschl *et al.*, 1990). However, high intensity fires can remove significant amounts of the total nutrient capital resulting in a depletion of a site's fertility (Groeschl *et al.*, 1990). In the case of high intensity southern pine fires, volatilization and eventual runoff once the forest floor was removed led to the lower total carbon levels. However, the translocation of carbon may have lead to increased levels in downslope positions. Soil pH also was found to increase following high intensity fires (Groeschl *et al.*, 1990).

3.8.2 Post-Fire Nitrogen Levels

Fire can affect soil nitrogen levels in two main ways: directly by volatilization and oxidation of nitrogen present in soil organic matter as well as indirectly by altering soil chemical and physical properties which affect soil nitrogen transformations (Mroz *et al.*, 1980; Wells *et al.*, 1979). Nitrogen is easily volatilized during combustion because it can be released from the organic matter in the form of nitrogen gas or nitrogen oxides (McNabb and Cromack, Jr., 1990).

Macadam (1989) noted that nitrogen may be the most limiting nutrient in British Columbia's forests, partly because the soils are relatively "young". While more than 90% of the nitrogen in the forests are associated with organic materials, less than 2% of the total content of nitrogen is in a form usable to plants (Macadam, 1989). More than one-third of the total nitrogen in the SBS may be found to a depth of 30 cm from the forest floor making this nutrient very susceptible to volatilization during combustion (Macadam, 1987). However, in the SBS, low soil temperature may be more limiting than low nutrient levels. The loss of nutrients from volatilization during the burning of the forest floor may be outweighed by the amelioration of the microclimate as higher soil temperatures make conditions better for plant growth. A post-fire increase in soil temperature of 10°C can provide the opportunity for conifer seedling survival (Macadam, 1987; Silversides *et al.*, 1986). This was confirmed by Ballard and Hawkes (1989) who studied 5 - 16 year-old planted white spruce in the McLeod Lake area of the SBS north of Prince George. They determined that spruce trees planted on burned sites would grow faster than those on unburned sites even though they showed nitrogen deficiencies.

Studies tend to show an immediate loss of total nitrogen contents due to volatilization accompanied with an increase the concentrations of available forms of nitrogen which are mobilized from the burned woody plants, the forest floor litter, duff layer and the microbial biomass (Beese, 1992; Christensen, 1973; Curran, 1994; Feller, 1982; Kutiel and Naveh, 1987; Mroz *et al.*, 1980; Okano, 1990; Wells *et al.*, 1979). A summary of reported changes in nitrogen levels due to fire events are provided from selected studies in Table 3.9.

Vitousek *et al.* (1989) suggest that, in many ecosystems, the levels of total nitrogen may increase or decrease naturally during late secondary succession. This would have ramifications in determining how much nitrogen may be mineralized during a fire. It was suggested that the severity of the climate would be a regulator in determining the naturally occurring background changes in mineralizable nitrogen during seral stage.

Fyles *et al.* (1991a) determined annual nitrogen mineralization rates in a forest within the Coastal Western Hemlock biogeoclimatic zone on Vancouver Island to range from 20 to 60 kg/ha/yr two years following prescribed fires. These levels were expected to support plantation growth provided the areas were not treated with a severe prescribed burn (high depth-of-burn) or occurred on coarse-textured soils. The soil was described as well-drained Humo-Ferric Podzols developed on loamy glacial till or colluvium which are also common in the SBS zone (Coupé *et al.*, 1991; Meidinger *et al.*, 1991).

Table 3.9 Change in nitrogen levels following fire events.

Ecosystem/Location	Time Period	Form of Nitrogen	Change	Reference
Coastal BC	- immediately post-fire	Total N	↓ 10% (216 kg/ha) for lowest impact burn ↓ 81% (1328 kg/ha) for highest impact burn ↓ 61-88% represented in loss of forest floor	Beese, 1992
California chaparral	- immediately post-fire	Total N	- decrease to 2.7 mg/g from 3.0 mg/g soil	Christensen, 1973
	- first rainfall post-fire (6 mm rain)	NO_3^--N	- 40-50 µg/ml leached	
	- subsequent rainfall	NO_3^--N	- none	
Cowichan Lake, BC	- 30 years post-fire (slash and burn)	forest floor N	- returned to within 0.5% of pre-fire levels	Curran, 1994
Entiat Valley/ Washington	- immediately post-fire	forest floor N	↓97%	Grier, 1975
		A horizon Total N	↓33%	
Aleppo pine/Israel	- immediately post-fire	Total N	↓ 25%	Kutiel and Naveh, 1987
	- 3 months post-fire	Total N	- return to pre-fire levels	
	- 8 months post-fire	NH_4^+-N	- 2X pre-fire levels	
Red Pine/Michigan	- 3 days post-fire	NH_4^+-N	↑ 76.6%	Mroz *et al.*, 1980 (laboratory analysis)
		NO_3^--N	↑ 36.8%	
		Total N	↓ 10.4%	
		available N	- increase from 0.93% to 1.55%	
	- 5 weeks post-fire	available N	- returned to pre-fire levels	
Eastern Hemlock/ Michigan	- 3 days post-fire	NH_4^+-N	↑ 2.2%	
		NO_3^--N	↑ 49.6%	
		Total N	↓ 8.5%	
		available N	- increase from 0.71% to 0.93%	
	- 5 weeks post-fire	available N	- returned to pre-fire levels	
Douglas-fir-western larch/Montana	- 3 days post-fire	NH_4^+-N	↓ 17.2%	
		NO_3^--N	↑ 24.2%	
		Total N	↓ 3.2%	
		available N	- decrease from 1.04% to 1.03%	
	- 5 weeks post-fire	available N	- returned to pre-fire levels	

Sub-Boreal Spruce/ B.C.	- immediately post-fire (slash-burning)	Total N	↓ 44% (470 kg/ha) from mesic, low impact site ↓ 46% (650 kg/ha) from mesic, moderate impact site ↓ 4% (156 kg/ha) from subhygric/hygric, low impact site ↓ 9% (358 kg/ha) from subhygric/hygric, moderate impact site	Taylor and Feller, 1986
Western Oregon	- immediately post-fire	NO_3^--N	- losses of 0.92 kg/ha following broadcast burning following clearcut compared to 0.05 kg/ha on undisturbed forest	Wells *et al.*, 1979
Ponderosa pine	- immediately post-fire	Total N	- loss of 140 kg/ha	
Loblolly pine	- immediately post-fire	Total N	- loss of 112 kg/ha	
Douglas-fir/ Washington	- immediately post-fire from slash-burning	Total N	- loss of 750 kg/ha	
Conifer forest/ Washington	- immediately post-fire	Total N	- loss of 907 kg/ha	
chaparral	- immediately following prescribed burn	Total N	↓ 10%	
Pine (species not specified for laboratory study)	- immediately post-fire	NH_4^+-N	- increase of 24 kg/ha	
Tobosagrass/Texas	- 5 years post-fire	litter-N	- returned to pre-fire levels	
Fir (species unspecified)	- 7 years post-fire	Total N	- returned to pre-fire levels due to N-fixation	

Note: ↓ = loss, ↑ = increase compared to pre-fire levels.

Feller and Kimmins (1984) have noted that natural nitrogen replacement in southwestern British Columbia occurs at levels of 4 kg/ha/yr through precipitation and less than 0.1 kg/ha/yr from mineral weathering. It remains unclear as to whether these rates are sufficient to replace all the nitrogen lost from a slash-burned area if an 80-year stand rotation is expected.

Fyles *et al.* (1991a) felt a consideration of the spatial pattern of mineralizable nitrogen following forest fires was required. Stand development reacts less favourably in areas where mineralizable nitrogen has accumulated in a thick humus layer encompassing small areas compared to sites where a thin humus layer has a more homogenous pattern. In the most severely burned area of their study, 50% of the mineralizable nitrogen encompassed only 5% of the burned area.

Studies have shown that biomass and nitrogen levels in Pacific Northwest forests tend to increase in all above-ground components of young forests with the relative distribution between crown and stem remaining somewhat similar. The colder and moister the system, the longer the period of time in which the biomass will have to accumulate and trap nitrogen. Release of the vital nitrogen requires cycling by soil organisms, precipitation or oxidation by fire (McNabb and Cromack, Jr., 1990).

In their study of the Douglas-fir/western larch forest, Mroz *et al.* (1980) found that ammonium and nitrate in the litter can be assimilated by increased microbial activity within three days of the fire event. However, the opposite was found in red pine (*Pinus resinosa*) and eastern hemlock (*Tsuga canadensis*) samples. As such, Mroz *et al.* (1980) concluded that generalizations of the effects of fire on soil nitrogen over large areas having different forest floor materials would be invalid. An example they presented was the much larger amount of nitrogen found in the litter of a Douglas fir/western larch forest as compared to a hemlock or red pine forest.

In their research of prescribed burning in ponderosa pine forests which are dominated by surface fire regimes, Ryan and Covington (1986, in Steele, 1994) discovered levels of ammonium that were as much as 80 times higher than similar unburned stands.

Levels of total carbon and nitrogen following southern pine forest fires were found to react differently according to the intensity of the fire (Groeschl *et al.* 1990). They found that low intensity burns caused total carbon and nitrogen to increase in the upper mineral soil layers from the pre-fire levels. The increase in total carbon was due to the redistribution and leaching of colloidal-sized charred material from the residual ash by gravity and water. Increases in total nitrogen were believed to have been correlated to increased carbon levels during N_2-fixation. Stevenson (1986, in Groeschl *et al.*, 1990) found that N_2-fixation could account for as much as 100 kg/ha/yr. Other studies in different types of ecosystems showed similar results (i.e. Christensen, 1973 in California chaparral; Viro, 1974 in Finland; as well as others mentioned in Mroz *et al.*, 1980; and in Wells *et al.*, 1979).

While increases in nitrate levels have been found following forest fires, Christensen (1973) noted that nitrate levels before and after fires in the California chaparral system were "nearly equal" and the study of Kutiel and Naveh (1987) in an Aleppo pine system in Israel indicated that the nitrate increases were the result of greater mineralization rates following the fire and not due to the burning. It should be cautioned that these results are from Mediterranean ecosystems and may not be transferrable to temperate systems.

The work of Fenn *et al.* (1993) has shown that post-fire ammonium concentrations in soils were found to be significantly higher over the initial two-year period following the burn, then declined. It was also shown that total nitrogen and mineralizable nitrogen increased with stand age up to 50-60 years in a Mediterranean chaparral ecosystem, then decreased. However, ammonium concentrations increased for only the first two years following the fire, after which they returned to pre-fire levels. They also noted the different effects of different tree species on the levels of nitrogen in the soil.

In their study in an Aleppo pine forest in Israel, Kutiel and Naveh (1987) found that total nitrogen dropped by 25% immediately following a fire. However, they also discovered that the total nitrogen had returned to its pre-fire levels within a few months of the burn.

It should be noted that some studies have shown that total nitrogen has not always been found to increase in underlying soil layers following forest fires (see Isaac and Hopkins, 1937 in Mroz *et al.*, 1980).

3.9 Summary of Soil/Fire Interactions

Many parameters affect how an ecosystem will react following a fire. Fire regime, depth-of-burn, site geography (aspect, slope, hydrology), types of forests, types of available fuels and fuel loading and consumption, vegetation and climate all must be considered when examining fire effects. Furthermore, when studying forest fires, researchers and forest managers must take into account the spatial context of historic fire patterns: fires traditionally did not operate solely on a stand-by-stand basis though that is reflected in many current stand management practices (Mutch, 1994). While subalpine and boreal ecosystems in Canada are not expected to maintain specific species compositions for periods of over 500 years (Johnson *et al.*, 1995), current fire suppression practices are attempting (indirectly) to make this happen by not viewing these forests as dynamic systems. Forest harvesting is supplementing the cycling by fire in many of these ecosystems.

Examination of the fire record for the McGregor Model Forest from 1951 to 1991 indicates a pattern of small (less than 0.1 ha) fires occurring over the entire landscape. A few large fires, however, were found to dominate fire-caused changes in the landscape.

Different ecosystems, and indeed different areas within ecosystems, react differently to fire with respect to nitrogen transformations. An immediate loss in total nitrogen has been found by many studies to coincide with immediate increases in available nitrogen, particularly nitrate. Whether a decrease in total nitrogen will affect the long term soil and tree productivity will depend on site characteristics such as nutrient and moisture status. In Lindeburgh's (1990) review of the effects of prescribed fire on site productivity, two main conclusions were made; (1) less severe fires showed less of a risk of causing site degradation than fires of higher severity, and; (2) drier, nutrient-poor sites were more likely to be degraded than moister, nutrient-rich sites.

Chapter Four - MATERIALS AND METHODS

4.1 Soils of the McGregor Model Forest: ARC/INFO Database Preparation

The database was created in ARC/INFO, a GIS which is commonly used by British Columbia's government agencies and the corporate sector. The project was prepared in a UNIX based Silicon Graphics Incorporated format.

The polygon structure was digitized from soils and surficial geology maps which were prepared by the Ministries of Agriculture, Forestry and the Environment in the 1960s and 1970s. Four soil survey reports (B.C. Soil Survey Reports 2, 4, 10, 23) and six surficial geology and landform maps which had been superimposed upon Canadian National Topographic System maps (93-I/3, 93-I/4, 93-J/1, 93-J/2, 93-J/7, 93-J/8) were used (Dawson, 1989; Farstad and Liard, 1954; Hortie *et al.,* 1970; Kelly and Farstad, 1946). All soil mapping which led to the soil survey reports were completed at the reconnaissance level through the use of aerial photographs and, therefore, meant for use in overview management decision making rather than site level diagnostics (Dawson, 1989). Original mapping was conducted on 1:100,000 scale National Topographic Series maps having been based on aerial photographs. The attribute information (including soils series, general topography, parent material texture and drainage information) included in the INFO file was developed from these maps as well as from soil survey reports.

A spatial query was formulated to obtain the total number of polygons and the area they represented of the soil associations representing the study sites within the McGregor Model Forest. This information was to be used for the nitrogen projections.

4.2 Site Selection

The sites were chosen as part of an investigation into the ecological processes operating within the McGregor Model Forest. Each site (1) was part of the same biogeoclimatic subzone (SBSvk1) in order to minimize variations in precipitation, temperature and vegetation; (2) had mesic/subhygric moisture regimes in order to minimize hydrologic variations; (3) showed no evidence of prior tree cutting due to harvesting or thinning operations, and; (4) was at least 20 m - 30 m from obvious clearings, stands of other ages or stands not meeting the aforementioned criteria. The sample area at each site was defined by a 30 m x 30 m quadrat (Delong *et al*., 1994). While it was the intention of this study to select all sites from within the MMF, this was not possible due to the difficulty in locating recently burned (which had not been salvage logged) and old growth post-fire sites. Therefore, to satisfy statistical requirements for the nitrogen analyses, three additional sites were selected outside the MMF. Also, two additional pedons were investigated at Site 11 in order to examine variations in soil properties on a catena formed on a relict avalanche.

A Scoutmaster II GPS (global positioning system) was used to record the latitude and longitude of each site. Figure 2.1 shows the locations of the 10 pedons within the MMF, the four pedons described in the Table River area about 25 km north of the MMF and the one described in the Gleason Creek area 10 km to the east of Pass Lake.

4.3 Sample Collection and Preparation

Pedons measured at least 1 m in width and were dug to depths revealing at least the top 25 cm of the C horizons (Agriculture Canada Expert Committee on Soil Survey, 1987). Field profile descriptions were completed for both the mineral and forest floor horizons (Expert Committee on Soil

Survey, 1983; Green *et al.,* 1993). Soil samples were collected from each of the horizons revealed within the pedon and refrigerated at 4°C prior to drying. Once air dried, the samples were passed through a 2000 μm (10 mesh) sieve to remove coarse fragments and were then stored in sealed Mason jars until required for each of the analyses.

Four composite samples were collected from the A and B horizons for the nitrogen analyses. These were composed of a mixture of soil from eight points within the quadrat. The points were located at one-third and two-thirds the distance between each of the four corners of the study quadrat. These samples were refrigerated until air drying was possible.

Three forest floor samples were collected from each of the sites for use in the nitrogen analyses. Each sample was refrigerated at 4°C then air dried for analysis. Where possible, roots and non-decomposed woody materials were removed from these samples. L, F and H horizons were separated prior to the analyses and ground to pass through a 425 μm (40 mesh) sieve. Where boundaries between forest floor horizons were not easily discernible, or there were insufficient amounts of horizons for analysis, horizon samples were combined and designated as the lower horizon.

4.4 Soil Temperature

Mean annual soil temperature was calculated from climate data prepared for the McGregor Model Forest (Murphy, 1995). In each case, the diabatic lapse rate was represented by a decrease in temperature of 0.6°C per 100 metre change in elevation from the base level (mean annual temperature = 2.5°C at 610 m.a.s.l.) obtained for the McGregor climate site (Murphy, 1995). A value of 1° C was then added to the mean annual air temperature to obtain the mean annual soil temperature (Soil Survey Staff, 1994).

4.5 Soil Characterization

4.5.1 Particle Size Analysis

Fifty grams of soil sample was immersed in 200 ml of deionized water (dH_2O) and subjected to an ultrasonic probe (set at 100 MHz) for six minutes to ensure the proper dispersion of the soil particles. This dispersed solution was then brought to a volume of 1000 ml with deionized water and thoroughly stirred. After seven hours, 20 ml of solution was removed at a depth of 10 cm by pipette and allowed to dry to determine the amount of the clay fraction. The remaining solution, and settled particles, were wet sieved with a 53 μm sieve to separate the sand from the silt and the remaining clay fractions. The sand fraction remaining in the sieve was dried and weighed. The percentage of silt in the sample was determined by subtracting the clay and sand values from the initial 50 g sample (Kalra and Maynard, 1991).

4.5.2 pH

pH was measured in a 2:1 ratio of 0.01M calcium chloride ($CaCl_2{\cdot}2H_20$) to soil as well as a 2:1 ratio of dH_2O to soil using a Fisher ACCUMET pH Meter Model 600. In each case, 10 g of soil was used (Hendershot *et al.*, 1993).

4.5.3 Exchangeable Cations and Cation Exchange Capacity

Concentrations of exchangeable cations (Al, Ca, Fe, K, Mg, Mn, Na) were determined for the mineral soil horizon samples using modifications of the ammonium acetate (NH_4OAc) method described by Hendershot *et al.* (1993). Twenty ml 1N NH_4OAc pH 7.0 was added to 5 g soil sample and further extractants were reduced by 50% throughout the procedure due to the low requirements of the

Leeman Labs PS Series ICP Spectrometer PS1000UV.

The Cation Exchange Capacity (CEC) was determined from 25 g of soil using the method described by Kalra and Maynard (1991) in which the exchange sites were saturated by unbuffered ammonium chloride (NH_4Cl). The total adsorbed ammonium (NH_4^+) was leached by NaCl and the level of ammonium in the leachate was determined by autoanalyser and was regarded as an estimate of the cation exchange capacity.

4.5.4 Extractable Fe and Al

Levels of extractable Fe and Al from the soil mineral horizon samples were determined by sodium pyrophosphate (0.1*M* $Na_4P_2O_7 \cdot 10H_2O$) and ammonium oxalate (0.2*M* $(NH_4)_2C_2O_4$) extractions. The optical density of the ammonium oxalate extracts also was measured.

Sodium pyrophosphate extraction followed the procedure described by Kalra and Maynard (1991) in which the soil samples and extracting solution are combined in centrifuge tubes, shaken for 16 hours and centrifuged for 10 minutes at 13,000 rpm prior to analysis for Fe and Al using the Leeman Labs PS Series ICP Spectrometer PS1000UV. Modifications included the use of 1 g of soil and 40 ml extracting solution.

Ammonium oxalate extraction of Fe and Al followed the procedure set out by the USDA (Soil Conservation Service, 1972). One gram of soil was combined with 40 ml extracting solution (0.2*M* oxalic acid at pH 3.0) in a centrifuge tube, shaken for 4 hours and centrifuged for 10 minutes at 13,000 rpm. The supernatant was then analysed for Fe and Al using the Leeman Labs PS Series ICP Spectrometer PS1000UV.

The Optical Density of Oxalate Extract (ODOE) was determined using extracts obtained in the ammonium oxalate procedure following the methods of Daly (1982). The optical density of the extracts were recorded as absorbance at a wavelength of 350 nm using the Perkin Elmer UV/VIS Spectrometer Lambda 2S.

4.6 Soil Classification

Fifteen pedons were classified using both the Canadian System of Soil Classification (Agriculture Canada Expert Committee on Soil Survey, 1987) and the USDA Soil Taxonomy (Soil Survey Staff, 1994). The diagnostic horizons and other soil characteristics for each pedon were determined based on profile descriptions from field examinations as well as physical and chemical data obtained in the laboratory. Following the keys to soil classification, each of the pedons was classified into soil orders, soil great groups and subgroups in the Canadian System and from the soil orders through the suborders and great groups to the subgroups in the USDA Soil Taxonomy.

4.7 Nitrogen Analyses

Levels of soil nitrogen (total N, C/N ratio, available NH_4^+, NO_3^-, mineralizable N) were determined for the A and B horizon composite samples and the forest floor samples: 54 A horizon, 54 B horizon and 80 forest floor samples were analysed.

4.7.1 Total N and C/N Ratio

Total nitrogen and total carbon analyses were conducted on a Carlo Erba NA1500 Elemental Analyser using elemental standard Atropine (Fisons Instruments, 1994). This autoanalyser used flash combustion at 1020°C in an enriched oxygen atmosphere to ensure complete oxidization of the samples.

The samples then were passed through two filters prior to passing through a chromatographic column which measured the thermal conductivity of the gas providing an electrical charge which had been calibrated to the levels of the two components being studied. We used 30-60 mg mineral soil samples (which had been passed through a 150 μm (100 mesh) sieve to ensure uniformity of sample) and 5-10 mg forest floor samples. The method has a detection limit of 0.01% for total nitrogen and carbon. Values for one sample from the A horizon was below the detection limit and was reported as one-half of the detection limit.

4.7.2 Available NO_3^- and NH_4^+

Available NO_3^- and NH_4^+ were determined to estimate the available nitrogen in the mineral soil and forest floor samples. Extraction of NO_3^- and NH_4^+ was conducted using air-dried samples following the 2.0*M* KCl method described by Maynard and Kalra (1993). Determination of available N levels were conducted using the autoanalyzer. Values of available NO_3^- which were below detection limits were reported as 0.005 ppm, one-half the detection limit of the autoanalyser.

4.7.3 Mineralizable N

Mineralizable N levels were determined using the procedure suggested by Powers (1980). Five grams of mineral soil sample (1 g forest floor sample) was measured and placed into test tubes to which 12.5 ml dH_2O was added. The sample was shaken, stoppered and incubated anaerobically for two weeks at 30°C. The sample was poured into a distillation flask, rinsed with 12.5 ml 0.4*N* KCl and 0.25 g MgO and allowed to boil until 25 ml of NH_4^+ distillate had been trapped in 5 ml of boric acid indicator solution (as described by Bremner and Mulvaney, 1982). Titration was conducted using 0.01*M* HCl.

4.7.4 Projection of Nitrogen Concentrations

ARC/INFO was used to create a coverage reflecting potential nitrogen values based on the soil series, forest age classes and biogeoclimatic subzone of the study areas. Three existing McGregor Model Forest coverages were used in this process. The first coverage was from the soils database discussed in section 4.1 which selected the primary and secondary soil series representing each of the study areas: "AVERIL" and "DOMINION"; "DOMINION" and "AVERIL"; "BPRIDGE" and "CAPTCREEK". The second coverage included forest age classes: "<20 years" was used to represent the Early Seral age class; "40-80 years" was used to represent the Mid-Seral age class; ">141 years" was used to represent the Late Seral age class. The third coverage was the SBSvk biogeoclimatic subzone. Once the new coverage was created, the areas of each of the nine selected regions and their percentage area covered of the McGregor Model Forest were determined in ARCPLOT. The ranges of nitrogen (total N, mineralizable N, available NH_4^+ and NO_3^-, C/N Ratio) values for each of the selected regions within the new coverage were determined from the various nitrogen analyses. Finally, a map is produced from the created coverage depicting the determined nitrogen projections.

4.8 Statistical Analyses

Nitrogen levels were compared between forest stands less than 14 years (Early Seral sites 5, 6, 9, 13) following a fire event, stands between 53 and 80 years (Mid-Seral sites 1, 3, 7, 10, 11) following a fire event and stands which have not experienced a fire event for more than 140 years (Late Seral sites 2, 4, 8, 12). Since the region experiences cycles of disturbance, the sites which were aged over 140 years were considered to have reached a state comparable to pre-fire levels.

Since the samples did not prove to be normally distributed, the One-Way ANOVA statistical test was not a valid tool in this analysis (Griffith and Amrhein, 1991). As such, the non-parametric Kruskal-Wallis H Test was used to examine the variation between the nitrogen levels of the different age classes separately for each of the forest floor and mineral horizons. Tests were conducted independently for each horizon and for each type of nitrogen (total, available and mineralizable nitrogen). A 95% confidence interval was used in all tests. The results of the Kruskal-Wallis H-Tests should give an indication of the levels of change experienced by the different horizons for each age class. Significant differences in the ranked data of available nitrogen would indicate that the ecosystem had not yet achieved a state of equilibrium following the previous forest fire. In cases where significant differences were determined by Kruskal-Wallis analysis, Fisher's Least Significant Difference (LSD) test was conducted as a *post hoc* investigation to determine which of the age classes were dissimilar.

A general linear model (GLM) was formulated using MINITAB® which approximated a two-way analysis of variance examining the interaction between age and horizon on the ranked levels of the different forms of nitrogen. The two-way analysis of variance function was not usable with the laboratory results as the data were not normally distributed (Griffith and Amrhein, 1991). This model grouped the means of the ranked data in tabular form following a structure similar to that of (and providing results approaching those of) the two-way analysis of variance.

Two hypotheses were examined for each of the five forms of nitrogen (total N, mineralizable N, available NH_4^+ and NO_3^-, C/N Ratio) examined in this section. The first examined the differences between the age classes and the second looked for interactions between the age classes and the soil horizons. The degrees of freedom and critical F values were determined from tables provided by Griffith and Amrhein (1991). As with the Kruskal-Wallis H-Test used above, clustering of the ranks was examined. The primary purpose of this part of the statistical analysis was to look for interactions between the age and horizon effects.

Chapter 5 - RESULTS AND DISCUSSION

5.1 ARC/INFO Database

The ARC/INFO database contains 1024 polygons, 288 of which contain soil information; the remainder represent mostly small water bodies. Soil associations, topography, soil texture, parent material texture and drainage data are included in the INFO files. Most of the polygons contain varying percentages of more than one soil association. This reflects the heterogenous nature of soils in the model forest. Available information on the study sites is presented in Table 2.1 and information on all the soil associations located within the McGregor Model Forest (MMF) is in Table 3.2. Table 5.1 provides spatial details of the dominant associations of these sites. The Barton soil association and the Dezaiko 2 + Captain Creek 2 complex do not occur within the MMF and have not been described.

Table 5.1 Spatial query of the ARC/INFO database of the dominant soil associations in the study sites within the MMF.

Soil Associations	Number of Polygons	Approximate Area Represented (ha)	Fraction of Total Area (%)
Averil 1 + Dominion 2	25	17000	9.0
Bearpaw Ridge + Captain Creek	7	6400	3.5
Dominion 2 + Averil 1	35	33000	18
Torpy River 2 + Dome Creek 1	1	320	0.18

5.2 Soil Classification and Pedon Characteristics

Five pedons are classified as Eluviated Dystric Brunisols, two as a Gleyed Eluviated Dystric Brunisols, five as Orthic Humo-Ferric Podzols, two as Orthic Gray Luvisols, and one as a Rego Humic Gleysol. In the USDA Soil Taxonomy, eight pedons are classified as Typic Haplocryods, three as Typic Cryochrepts, one Oxyaquic Cryochrept, one Typic Cryoboralf, one Typic Cryaquod and one Oxyaquic Cryoboroll. Table 5.2 is a summary of the classifications for each of the study pedons.

Table 5.2 Soil Classifications for each of the study pedons.

Pedon	Canadian System of Soil Classification	USDA Soil Taxonomy
1	Eluviated Dystric Brunisol	Typic Cryochrept
2	Orthic Humo-Ferric Podzol	Typic Haplocryod
3	Eluviated Dystric Brunisol	Typic Cryochrept
4	Eluviated Dystric Brunisol	Typic Haplocryod
5	Orthic Gray Luvisol	Typic Cryoboralf
6	Gleyed Eluviated Dystric Brunisol	Typic Cryaquod
7	Orthic Humo-Ferric Podzol	Typic Haplocryod
8	Orthic Humo-Ferric Podzol	Typic Haplocryod
9	Orthic Humo-Ferric Podzol	Typic Haplocryod
10	Gleyed Eluviated Dystric Brunisol	Oxyaquic Cryochrept
11-U	Orthic Gray Luvisol	Typic Haplocryod
11-M	Eluviated Dystric Brunisol	Typic Haplocryod
11-L	Rego Humic Gleysol	Oxyaquic Cryoboroll
12	Eluviated Dystric Brunisol	Typic Haplocryod
13	Orthic Humo-Ferric Podzol	Typic Cryochrept

U = upper slope, M = mid-slope, L = lower slope

Each of the sites have similar soil moisture and temperature regimes because the study site selection was designed to minimize environmental differences between the different plots. With the exceptions of the microsite variation of the lower slope position of Site 11, all sites have udic moisture regimes as defined within the *Keys to Soil Taxonomy, Sixth Edition* (Soil Survey Staff, 1994). Also, each of the sites has a cryic soil temperature regime as determined by the calculations defined in section 4.4.

5.2.1 The Eluviated Dystric Brunisols

Pedons 1, 3, 4, 11 (middle slope) and 12 are classified as Eluviated Dystric Brunisols (E.DYB) (Typic Cryochrept and Typic Haplocryods). These soils have an Ae horizon and Bm (Bfj or Btj) horizon with $pH_{CaCl2} < 5.5$. The pH_{dH2O} ranges from 3.9 to 5.7, increasing from the A through C horizons in each of the pedons. The clay content is consistently below 10% throughout each of these pedons with the exception of Pedon 4 which ranges between 15.2% and 18.6% from the Ahe to the C horizon. The cation exchange capacity (CEC) is less than 9 cmol(+) kg^{-1} in all of the horizons with the highest CEC in the A horizon of Pedon 1 (8.9 cmol (+) kg^{-1}) and the lowest in the BC, IC and IIC horizons Pedon 11 (middle slope) (CEC = 1.1 cmol (+) kg^{-1}). The B horizons of the E.DYBs have CEC between 3.8 cmol(+) kg^{-1} and 7.0 cmol (+) kg^{-1}. The exchange complexes are dominated by Ca, Al and Mg with base saturations ranging from a low of 9.5% in the B horizon of Pedon 4 to a high of 85% in IIC horizon of Pedon 11 (middle slope). The sum of sodium pyrophosphate extractable Fe + Al ($Fe_p + Al_p$) ranges from < 0.1% in the A horizons to 0.22% - 0.44% in the B horizons.

The properties of these pedons do not meet the criteria of any of the diagnostic horizons within the Canadian System of Soil Classification (Agriculture Canada Expert Committee on Soil Survey, 1987). The results for the analysis of Pedon 1 are provided as an example of an E.DYB soil profile found within this region, including a photograph, a field description and selected physical/chemical properties (Figure 5.1 and Tables 5.3 and 5.4). The results for the remaining E.DYB pedons are in Appendices B (profile descriptions and diagnostic horizons/properties) and C (physical and chemical properties).

Having been mapped as members of the Dominion and Averil association and the Bearpaw Ridge and Captain Creek association, it was anticipated that Pedons 1, 3, 4 and 10 would be dominated by Orthic Humo-Ferric Podzols (O.HFP) with a significant inclusion of E.DYBs. In the case of Pedons 11 and 12, in which the Barton association is mapped, Orthic Ferro-Humic Podzols were expected. However, the distinction between the Brunisolic and Podzolic Orders within the Canadian System of Soil Classification results mainly from the podzolization process. Eluviated Dystric Brunisols do not have a sufficient amount of Fe_p and Al_p to meet the requirements for a podzolic B diagnostic horizon (Agriculture Canada Expert Committee on Soil Survey, 1987). With time, these E.DYB pedons may develop into podzolic soils as shown in the properties of Pedons 4 and 11(middle slope) which show a degree of podzolization based on their classification in the USDA Soil Taxonomy (Soil Survey Staff, 1994).

Pedons 4 and 11 (middle slope) have values for ammonium oxalate extractable Fe and Al (Fe_o and Al_o) and an optical density of oxalate extract (ODOE) indicative of some degree of podzolization (Appendix B). These two pedons are classified as Typic Haplocryods in the order Spodosols (the equivalent to the Podzolic Order) in Soil Taxonomy (Soil Survey Staff, 1994). The ODOE is an indication of a podzolization process because it extracts organic complexes of Fe and

Figure 5.1 Profile of Pedon 1, an Eluviated Dystric Brunisol.

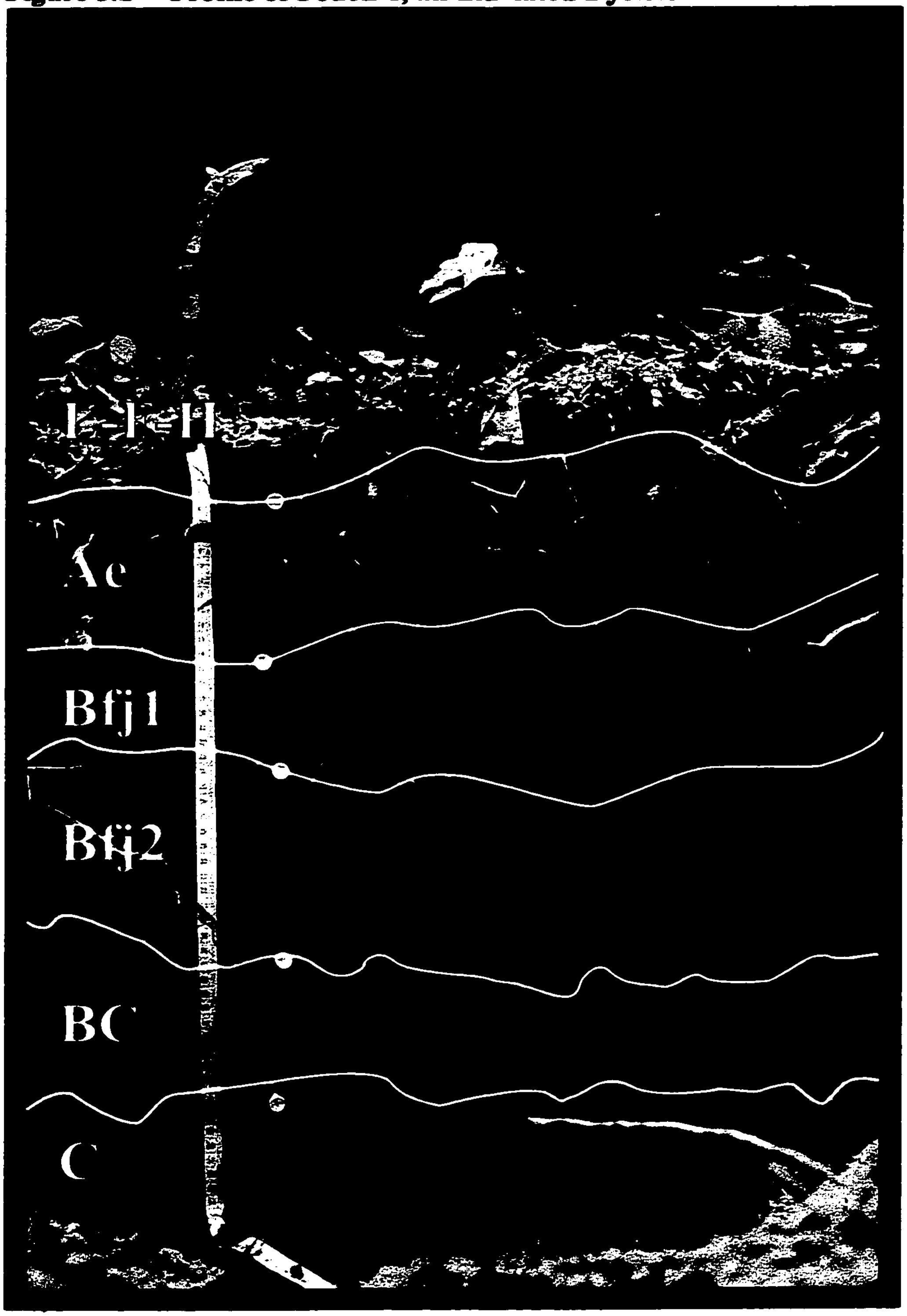


Table 5.3 Pedon 1 - Profile description, diagnostic horizons and/or properties typical of an Eluviated Dystric Brunisol found within the MMF.

Horizon	Depth (cm)	Description
S		Bryophytes
Ln	5-4	Deciduous leaves, coniferous needles, twigs, fungal mycelia.
Fm	4-2	Moist; black (5YR 2.5/1 m); moderate, compact matted, friable, leafy; few, fine roots; common, random fungal mycelia.
Hr	2-0	Moist; (5YR 2.5/1 m); strong, granular, friable, gritty; common, very fine roots; few, random fungal mycelia.
Ae	0-11	Very dark grayish brown (10YR 3/2 m); silt loam; strong, fine granular; friable; abundant, fine to coarse, random, inped and exped roots; charcoal fragments; clear, smooth boundary.
Bfj1	11-19	Strong brown (7.5YR 4/6 m); loam; moderate to strong, fine, subangular blocky; slightly friable; abundant, coarse to medium, vertical, inped and exped roots; gradual, smooth boundary.
Bfj2	19-32	Dark brown (7.5YR 3/4 m); loam; moderate to strong, fine, subangular blocky; slightly friable; plentiful, medium to coarse, vertical, inped and exped roots; gradual, smooth boundary.
BC	32-43	Dark yellowish brown (10YR 4/4 m); loam; moderate to strong, fine, subangular blocky; moderately friable; few, fine to medium, vertical, exped roots; gradual, smooth boundary.
C	43+	Very dark grayish brown (2.5Y 3/2 m); loam; very weak, medium, subangular blocky; slightly hard; very few, fine, vertical, exped roots.

Diagnostic Horizons and/or Properties.

Canadian System: *Eluviated Dystric Brunisol.*
Bfj horizon.
pH < 5.5 by 0.01M $CaCl_2$.
Ae horizon at least 2 cm thick.

U.S. Soil Taxonomy: *Typic Cryochrept.*
Epipedon: Ochric
Subsurface horizons: Albic, Cambic.
Subsurface materials: Albic.

Table 5.4 Pedon 1 - Selected physical and chemical properties of an Eluviated Dystric Brunisol found within the MMF.

HORIZON	Sand %	Clay %	Silt %	Texture Class	C %	N %	C/N	pH dH_2O	pH 0.01M $CaCl_2$
Ae	54.5	5.10	40.4	sandy loam	1.9	0.13	15	4.6	3.6
Bfj1	49.8	4.00	46.2	sandy loam	2.3	0.14	17	5.2	4.4
Bfj2	49.7	3.30	47.0	sandy loam	1.9	0.10	18	5.3	4.6
BC	53.6	3.70	42.7	sandy loam	1.7	0.086	20	5.5	4.6
C	51.8	5.90	42.3	sandy loam	0.76	0.056	14	5.7	4.8

HORIZON	Extractable Cations by NH_4OAc pH 7.0 (cmol(+)kg^{-1})								Base Sat.
	Al	Ca	Fe	K	Mg	Mn	Na	CEC	%
Ae	0.022#	3.1	0.011#	0.15	1.1	0.0070#	0.059	8.9	50
Bfj1	0.022#	2.8	0.011#	0.0050#	1.2	0.0070#	0.026	7.0	56
Bfj2	0.16	1.8	0.011#	0.0050#	0.60	0.0070#	0.045	4.1	60
BC	0.30	1.5	0.011#	0.13	0.36	0.0070#	0.033	3.4	60
C	0.19	0.89	0.011#	0.084	0.17	0.0070#	0.021	1.6	75

HORIZON	Al_p %	Fe_p %	Al_o %	Fe_o %	ODOE*	Fe_p+Al_p	(Fe_p+Al_p)/clay	org C/Fe_p	$.5Fe_o+Al_o$
Ae	0.024	0.073	0.041	0.085	0.63	0.097	0.019	26	0.083
Bfj1	0.13	0.33	0.21	0.26	1.6	0.46	0.12	7.1	0.34
Bfj2	0.17	0.26	0.26	0.13	1.2	0.42	0.13	7.0	0.32
BC	0.20	0.19	0.32	0.096	1.1	0.39	0.10	9.1	0.37
C	0.10	0.067	0.18	0.036	0.26	0.17	0.029	11	0.20

$_o = (NH_4)_2C_2O_4$ $_p = Na_4P_2O_7$ * = optical density of oxalate extract # = result lower than this detection limit

Al as well as the amorphous inorganic Fe and Al believed to be associated with imogolite, proto-imogolite and ferrihydrite (Daly, 1982; Wang, 1990). Recently, the formation of these inorganic amorphous Fe, Al (and Si) materials have been recognized as a major occurrence within podzolization processes in addition to the movement of organic matter with or without Fe and Al. In the USDA Soil Taxonomy, pedons 1 and 3 are classified as Typic Cryochrepts within the order Inceptisols (the equivalent of the Brunisolic Order in the Canadian System). Burns (1990) noted that high elevations and cold temperatures could slow biological and chemical processes to the point where illuviation of organometallic compounds would not be able to take place leading to the classification of Brunisols rather than Podzols.

5.2.2 The Orthic Humo-Ferric Podzols

Pedons 2, 7, 8, 9 and 13 are classified as Orthic Humo-Ferric Podzols (Typic Haplocryods and Typic Cryochrept). These pedons are more acidic than the Brunisols as the pH_{CaCl2} is consistently lower than the Brunisols ranging between 3.2 and 5.1 (pH_{dH2O} ranges from 4.2 - 6.1). The maximum clay content of the O.HFPs is 10.4% in Pedon 13 and is less than 3.5% in the majority of horizons. The CEC is less than 10 cmol(+) kg^{-1} in all but Pedon 13 which ranges from 12 cmol(+) kg^{-1} to 18 cmol(+) kg^{-1}. For the remaining O.HFPs, the B horizons have the highest CEC ranging from 3.4 cmol(+) kg^{-1} in the Bf2 horizon of Pedon 2 to 7.5 cmol(+) kg^{-1} in the Bf horizon of Pedon 9. The CEC for the Ae horizons ranges from 2.3 cmol(+) kg^{-1} in Pedon 8 to 9.9 cmol(+) kg^{-1} in Pedon 9 compared to a range of 1.3 cmol(+) kg^{-1} to 2.7 cmol(+) kg^{-1} in the C horizons (Pedon 9 and Pedon 2, respectively). Calcium is the dominant exchangeable cation of the O.HFPs with Mg providing the second highest levels. The remaining cations contribute to the exchange complex to a much lesser degree with many Fe and Mn values being below the detection limit of the laboratory equipment. Our results for exchangeable Ca, Mg and K are comparable to the figures presented by Kimmins and Hawkes (1978) in their study of post-harvest nutrient levels on podzols within the SBS zone northeast of Prince George. (However, our values for the Ae horizon are marginally higher than their reported values and our B horizon values tend to be lower than theirs.) Base saturation ranges from a low of 8.4% in Pedon 9 to full saturation in Pedon 13. Fe_p values are above 0.3% and the sum of Fe_p + Al_p are above 0.6% as required for the diagnostic podzolic B horizon within the Canadian System of Soil Classification (Agriculture Canada Expert Committee on Soil Survey, 1987).

Pedons 2, 7 and 8 have been mapped within the Averil 1 and Dominion 2 soil associations, though to differing degrees of each association. These Podzols are shown to have a smaller range of textures than the Brunisols within these associations as the Podzols range in texture from loam to sandy loam with sandy loam again being the dominant texture class. This is consistent with the particle size class of the parent materials reported for these areas (Dawson, 1989). Site 9 is part of the Torpy River 2 and Dome Creek 1 associations; these are moderately well to rapidly drained soils which are expected to develop into Eluviated Dystric Brunisols and Orthic Humo-Ferric Podzols. Site 13 is within the Dezaiko 2 and Captain Creek 2 associations which are dominated by Orthic Humo-Ferric Podzols.

Chemically, these pedons are similar to the E.DYBs but with a stronger degree of podzolization. Humo-Ferric Podzols are common on steep slopes in the interior of British Columbia (Young and Alley, 1978) and primarily are distinguished from the other Podzols by their higher Fe_p than observed in the Bh horizon of the Humic Podzols or the Bhf of the Ferro-Humic Podzols.

These other Podzols also occur under wetter conditions than the Humo-Ferric Podzol as the Humic Podzol may be found under saturated conditions and the Ferro-Humic Podzols are usually found under more humid conditions, such as on the coast of British Columbia. The Orthic Humo-Ferric Podzol is the modal soil for the Humo-Ferric Podzols. It is distinguished from the other Humo-Ferric Podzols by its light coloured A horizon, its lack of a cemented, duric, fragic or placic horizon as well as its lack of mottling or a Bt horizon within the top 50 cm of its profile (Agriculture Canada Expert Committee on Soil Survey, 1987).

Figure 5.2 is a photograph of Pedon 8 and is provided as an example of the O.HFPs which may be found in the region. The profile description and physical/chemical data for Pedon 8 are provided in Tables 5.5 and 5.6 and are representative of the other O.HFPs. Profile descriptions and results of the physical and chemical analyses for the remaining pedons have been provided as Appendices B and C.

Pedons 2, 7, 8 and 9 are all classified as Typic Haplocryods within the USDA Soil Taxonomy. This was anticipated as these belong to the Spodosol Order which, as has been previously mentioned, is the equivalent to the Podzolic Order in the Canadian System. However, Pedon 13 is classified as a Typic Cryochrept. In this case, the properties are not sufficient to satisfy the requirements of a spodic horizon; ODOE was above 0.25, but does not increase with depth, and the value of $0.5Fe_o + Al_o$ is below 0.5%, the minimum requirement.

5.2.3 The Orthic Gray Luvisols

Pedons 5 and 11 (upper slope) are classified as Orthic Gray Luvisols (Typic Cryoboralf and Typic Haplocryod). These pedons have Ae and Bt horizons. The pH_{CaCl2} ranges from 4.1 to 5.2

Figure 5.2 Profile of Pedon 9, an Orthic Humo-Ferric Podzol.

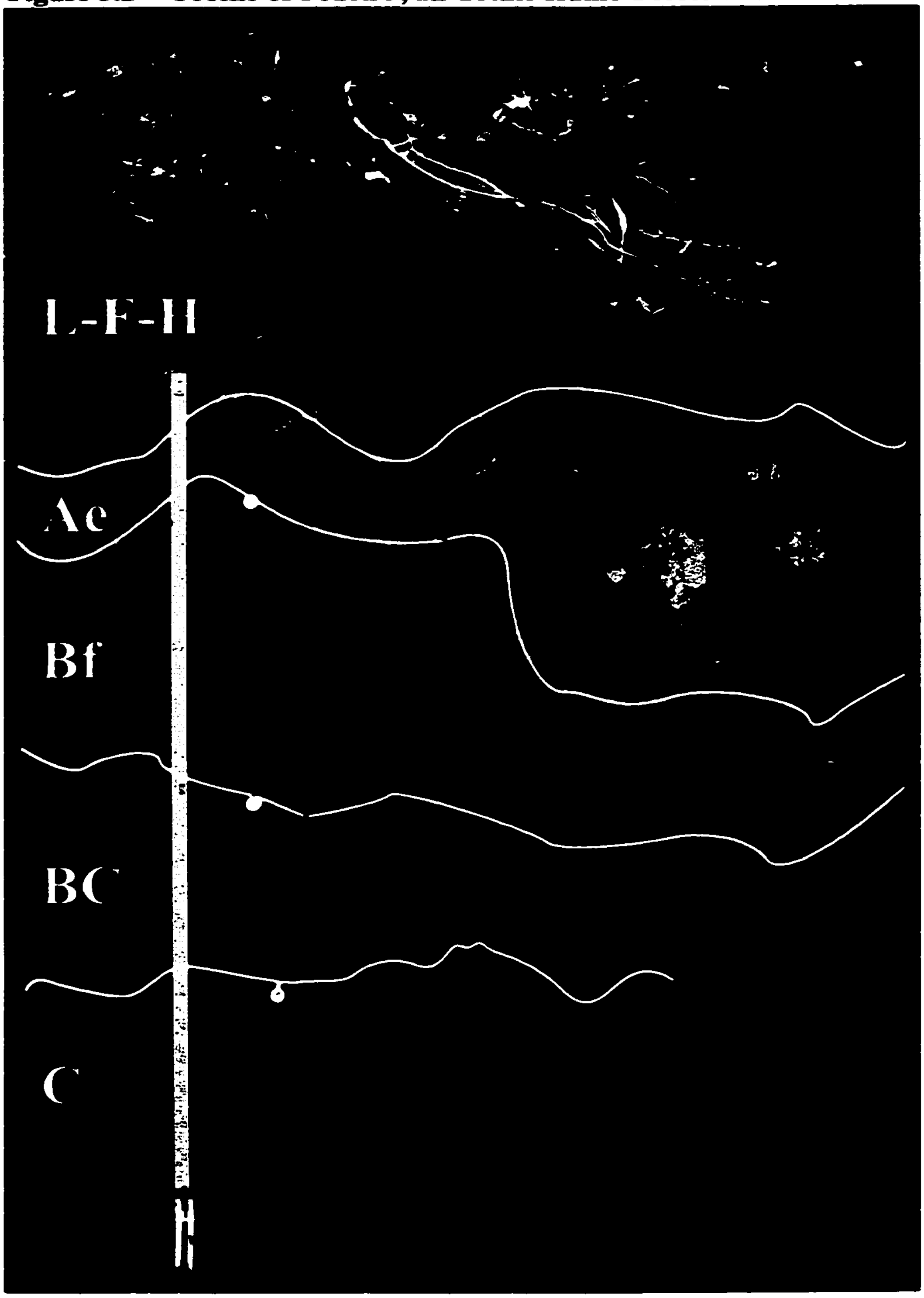


Table 5.5 Pedon 9 - Profile description, diagnostic horizons and/or properties typical of an Orthic Humo-Ferric Podzol found within the MMF.

Horizon	Depth (cm)	Description
S		Bryophytes.
Lv	6-4	Deciduous leaves, twigs, coniferous needles, fungal mycelia.
Fm	4-2	Moist; black (10YR 2/1 m); weak, compact matted, firm, fibrous; few, very fine roots; common *Annelida*; common, random fungal mycelia.
Hr	2-0	Moist; very dark brown (10YR 2/2 m); moderate, compact matted, firm, fibrous; common, very fine roots, common *Annelida*; few, random fungal mycelia.
Ae	0-10	Light brownish gray (10YR 6/2 m); silt loam; moderate, medium, subangular blocky; slightly hard; plentiful, medium, vertical, exped roots; clear, wavy boundary.
Bf	10-33	Yellowish red (5YR 4/6 m); silt loam; strong, fine to medium, subangular blocky; slightly hard; plentiful, medium to coarse, vertical, exped roots; gradual, wavy boundary.
BC	33-48	Dark yellowish brown (10YR 4/6 m); loamy sand; single grain; loose; plentiful, medium, vertical, exped roots; gradual, smooth boundary.
C	48+	Yellowish brown (10YR 5/8 m); loamy sand; single grain; loose; very few, fine and medium, vertical, exped roots.

Diagnostic Horizons and/or Properties.

Canadian System: Podzolic Bf horizon. Organic C = 0.5-5% Fe_p+Al_p = 0.6% or more. Base saturation < 50%	*Orthic Humo-Ferric Podzol.*
U.S. Soil Taxonomy: Epipedon: Ochric Subsurface horizons: Albic, Spodic. Subsurface materials: Albic, Spodic.	*Typic Haplocryod.*

Table 5.6 Pedon 9 - Selected physical and chemical properties of an Orthic Humo-Ferric Podzol found within the MMF.

HORIZON	Sand %	Clay %	Silt %	Texture Class	C %	N %	C/N	pH dH_2O	pH 0.01M $CaCl_2$
Ae	32.6	7	60.4	silt loam	0.49	0.010#	98	4.2	3.2
Bf	55.5	3	41.5	sandy loam	3.4	0.099	35	4.7	4
BC	84.2	1.8	14	loamy sand	1.3	0.062	21	4.8	4.3
C	86	1.6	12.4	sand/ loamy sand	1.4	0.057	24	5	4.4

HORIZON	Extractable Cations by NH_4OAc pH 7.0 (cmol(+)kg^{-1})								Base Sat.
	Al	Ca	Fe	K	Mg	Mn	Na	CEC	%
Ae	0.44	1.5	0.011#	0.16	0.24	0.048	0.022	9.9	19
Bf	0.59	0.49	0.042	0.11	0.074	0.010	0.028	7.5	9.4
BC	0.4	0.15	0.011#	0.0050#	0.017	0.0070#	0.014	2.2	8.4
C	0.24	0.1	0.011#	0.044	0.014	0.0070#	0.017	1.3	14

HORIZON	Al_p %	Fe_p %	Al_o %	Fe_o %	ODOE*	Fe_p+Al_p	(Fe_p+Al_p)/clay	org C/Fe_p	$.5Fe_o+Al_o$
Ae	0.019	0.014	0.048	0.023	0.08	0.033	0.005	34	0.059
Bf	0.31	0.63	0.61	0.42	2.7	0.95	0.32	5.4	0.82
BC	0.14	0.14	0.34	0.13	0.87	0.28	0.15	9.5	0.41
C	0.17	0.16	0.34	0.11	0.65	0.33	0.21	8.5	0.39

$_o$ = $(NH_4)_2C_2O_4$ $_p$ = $Na_4P_2O_7$ * = optical density of oxalate extract # = result lower than this detection limit

(pH_{dH2O} 4.7 to 6.4) in Pedon 5 and from 3.5 to 4.2 (pH_{dH2O} 4.3 to 4.7) in Pedon 11 (upper slope). The CEC is below 10 cmol(+) kg^{-1} in both pedons with the highest levels in the Bt horizon of Pedon 5 (9.9 cmol(+) kg^{-1}) and the lowest levels in the BC and C horizons (2.9 cmol(+) kg^{-1} and 1.6 cmol(+) kg^{-1}, respectively) of Pedon 11 (upper slope). Calcium again is the dominant cation ranging from 0.25 cmol(+) kg^{-1} in the C horizon of Pedon 11 (upper slope) to a high of 5.3 cmol(+) kg^{-1} in the BC horizon of Pedon 5. Base saturation is lowest in Pedon 11 (upper slope) with values not exceeding 34% and highest in Pedon 5 ranging from 37% in the Bt horizon to full saturation in the C horizon.

Properties representative of lessivage are used in the classification of these pedons. Clay levels increase from 5 - 12% from the Ae to Bt1 horizons in Pedon 5 and from 7.9 - 13.4% from the Ae to Bt horizons in Pedon 11 (upper slope). Since clay levels do not exceed 15% in either pedon, an increase from the A to B horizon of only 3% clay fraction is required to classify the B horizon as a Bt horizon, a characteristic of the Luvisolic Order (Agriculture Canada Expert Committee on Soil Survey, 1987).

The classification of Pedon 5 is unique as both the Bt1 and Bt2 horizons show considerable translocation of Fe_p and Al_p. If not for the change in clay levels between the Ae and Bt1 horizons, both of the Bt horizons would be classified as podzolic B horizons. However, within the Canadian System, the presence of a Bt horizon within the top 50 cm of the soil profile rules out the podzolic order (Agriculture Canada Expert Committee on Soil Survey, 1987). Pedon 5 also is found to belong to polygon 232 of the McGregor Soils ARC/INFO Database. This polygon is derived from a combination of the Dominion 2 (70%) and Averil 1 (30%) soil associations which are discussed in section 2.2. If not for the luvisolic properties of this pedon, the dominant Orthic Humo-Ferric Podzol classification of these associations would have been keyed.

Pedon 5 demonstrates a similarity between the American and Canadian systems of soil classification. Within the Canadian System, the Bt horizon (illuviation of clay) supersedes the podzolic B horizon (translocation of Fe_p and Al_p) leading to the Luvisolic Order (Agriculture Canada Expert Committee on Soil Survey, 1987). Similarly, the presence of the argillic diagnostic subsurface horizon prevents keying within the Spodosols in the Soil Taxonomy and leads to the keying within the Alfisol Order (Agriculture Canada Expert Committee on Soil Survey, 1987; Soil Survey Staff, 1994).

The classification of Pedon 11 (upper slope) demonstrates a difference between the Canadian and American approaches to classification. However, in the Soil Taxonomy, the argillic diagnostic subsurface horizon must be above the spodic diagnostic subsurface horizon in order to rule out the podzolization in keying the classification (Soil Survey Staff, 1994). In the case of Pedon 11 (upper slope), the Bt horizon is diagnosed as having both argillic and spodic properties leading to the keying of the Spodosol Order before the Alfisol Order could be keyed.

A photograph (Figure 5.3), profile description and physical/chemical data (Tables 5.7 and 5.8, respectively) for Pedon 5 follow as a representation of an O.GL which may be found within the MMF. The profile description and physical/chemical data for Pedon 11 (upper slope) are provided in Appendices B and C, respectively.

5.2.4 The Gleyed Eluviated Dystric Brunisols and the Rego Humic Gleysol

Pedons 6 and 10 are classified as a Gleyed Eluviated Dystric Brunisols (GLE.EDB) and Pedon 11 (lower slope) is classified as a Rego Humic Gleysol (R.HG). These gleyed pedons result from changes in microtopography. Pedons 6 and 10 meet all the aforementioned physical and

Figure 5.3 Profile of Pedon 5, an Orthic Gray Luvisol.

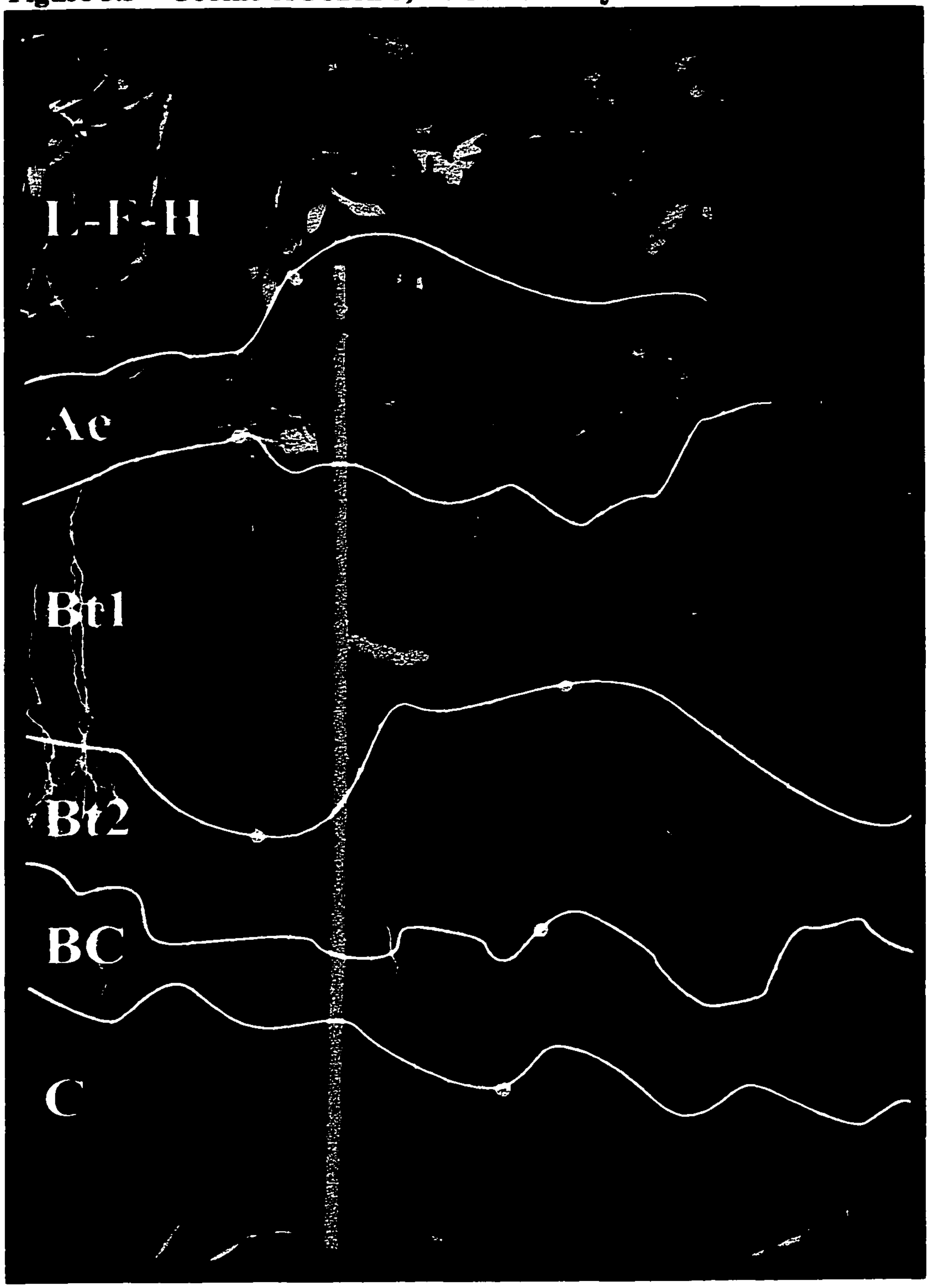


Table 5.7 Pedon 5 - Profile description, diagnostic horizons and/or properties typical of an Orthic Gray Luvisol found within the MMF.

Horizon	Depth (cm)	Description
Lv	7-6	Twigs, deciduous leaves, coniferous needles.
Hr	6-0	Moist; black (10YR 2/1 m); weak, granular, firm, greasy; abundant, fine roots; few *Myriapoda*; few, random droppings.
Ae	0-15	Grayish brown (10YR 5/2 m); sandy loam; single grain; loose; abundant, coarse, random, exped roots; clear, wavy boundary.
Bt1	15-35	Dark brown (7.5YR 3/4 m); loam; strong, fine to medium, subangular blocky; friable; plentiful, fine to coarse, random, exped roots; clear, wavy boundary.
Bt2	35-55	Strong brown (7.5YR 4/6 m); sandy loam; moderate, fine to medium, subangular blocky; friable; plentiful, medium, vertical, exped roots; gradual, wavy boundary.
BC	55-69	Dark brown (10YR 3/3 m); loamy sand; moderate, medium, subangular blocky; slightly friable; plentiful, fine to medium, vertical, exped roots; gradual, smooth boundary.
C	69+	Olive brown (2.5Y 4/4 m); sand; massive; slightly hard; many, fine to medium, vertical, exped roots.

Diagnostic Horizons and/or Properties.

Canadian System: Bt and eluvial horizons. Medium to fine textured soils.	*Orthic Gray Luvisol.*
U.S. Soil Taxonomy: Epipedon: Ochric Subsurface horizons: Albic, Argillic. Subsurface materials: Albic.	*Typic Cryoboralf.*

Table 5.8 Pedon 5 - Selected physical and chemical properties of an Orthic Gray Luvisol found within the MMF.

HORIZON	Sand %	Clay %	Silt %	Texture Class	C %	N %	C/N	pH dH_2O	pH 0.01M $CaCl_2$
Ae	59.8	5	35.2	sandy loam	1.1	0.064	18	5.3	4.5
Bt1	54.6	12.6	32.8	sandy loam	4.5	0.2	23	4.7	4.1
Bt2	57.7	10.4	31.9	sandy loam	4.2	0.1	42	5.3	4.6
BC	71.8	5.9	22.3	sandy loam	4.1	0.35	12	6.2	5.2
C	75.7	6.4	17.9	sandy loam	1.4	0.11	12	6.4	5.2

HORIZON	Extractable Cations by NH_4OAc pH 7.0 (cmol(+)kg^{-1})								Base Sat.
	Al	Ca	Fe	K	Mg	Mn	Na	CEC	%
Ae	0.022#	4.6	0.011#	0.11	1.9	0.011	0.013	7.9	84
Bt1	0.15	1.9	0.044	0.18	1.6	0.011	0.026	9.9	37
Bt2	0.41	3.5	0.023	0.1	1.3	0.015	0.033	7.6	65
BC	0.048	5.3	0.011#	0.038	0.99	0.0070#	0.02	6.6	96
C	0.022#	4.2	0.011#	0.01	0.94	0.0070#	0.014	4.7	saturated

HORIZON	Al_p %	Fe_p %	Al_o %	Fe_o %	ODOE*	Fe_p+Al_p	(Fe_p+Al_p)/clay	org C/Fe_p	$.5Fe_o+Al_o$
Ae	0.005	0.008	0.013	0.012	0.50	0.013	0.003	140	0.019
Bt1	0.260	0.63	0.45	0.56	3.2	0.89	0.071	7.2	0.73
Bt2	0.467	0.65	0.68	0.21	3	1.1	0.11	6.4	0.79
BC	0.289	0.19	0.48	0.084	2.4	0.48	0.081	21	0.52
C	0.07	0.059	0.099	0.037	0.43	0.13	0.020	23	0.12

$_o = (NH_4)_2C_2O_4$ $_p = Na_4P_2O_7$ * = optical density of oxalate extract # = result lower than this detection limit

chemical requirements of E.DYBs, however, mottling was observed in both the B and C horizons and water seepage was noted in a sand layer at a depth of 59 cm leading to the belief that periodic water saturation is a permanent feature of Pedon 6 and mottles were noted in the C horizon of Pedon 10. These pedons have pH_{CaCl2} between 3.8 and 5.1 and pH_{dH2O} from 4.5 to 6.2 increasing from the Ae to the Cg horizons. The clay content of these pedons was highest in the Bfj horizon (6.00%) of Pedon 10 and lowest in the Cg horizon (4.60%) of Pedon 6. As with all the E.DYBs and O.HFPs, Ca is the dominant cation in the exchange complex. Exchangeable Al and Fe are below detection limits in most horizons and exchangeable Mn is below the detection limit in the Btjg horizon of Pedon 6 and the Cg horizons of both pedons. CEC levels are similar to the E.DYBs ranging from 2.4 cmol(+) kg^{-1} to 8.9 cmol(+) kg^{-1}. Base saturation ranges from 32% to full saturation. Fe_p values do not exceed 0.35% and Fe_p+Al_p values do not exceed 0.44% in any of the horizons.

Pedon 11 (lower slope) is classified as a Rego Humic Gleysol. A digitized photograph, profile description and physical/chemical data are provided as Figure 5.4, Table 5.9 and Table 5.10. The pH, CEC and base saturation levels for this pedon are all higher than the majority of the E.DYB, O.HFP and O.GL values. This is an azonal soil which formed on colluvium at the base of a relict avalanche of which Pedon 11 (upper slope) and Pedon 11 (middle slope) are a part. The accumulated organic matter which came to rest at this point from the upper slope positions is a primary factor in leading to this classification. While this classification may not be dominant on the landscape of the study area, Humic Gleysols can be found in depressions below Humo-Ferric Podzols where seepage is extensive and water has been able to accumulate (Young and Alley 1978). King and Brewster (1978) demonstrated that environmental stresses occurring during the period of pedogenesis can change the pathway that a developing soil will follow. Their study showed the

Figure 5.4 Profile of Pedon 11 (lower slope), a Rego Humic Gleysol.

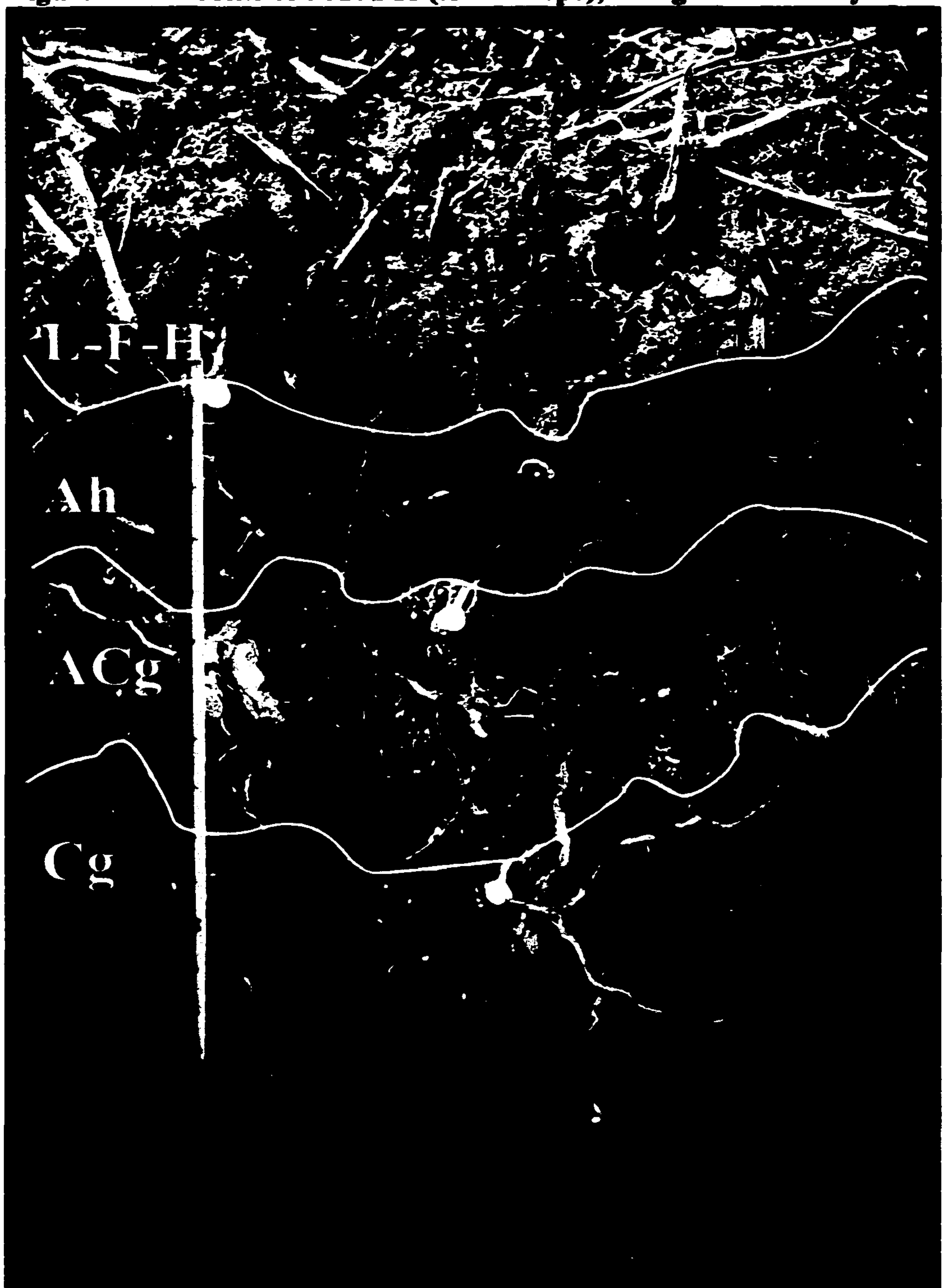


Table 5.9 Pedon 11 (lower slope) - Profile description, diagnostic horizons and/or properties typical of a Rego Humic Gleysol found north of the MMF.

Horizon	Depth (cm)	Description
Ln	16-14	Deciduous leaves, coniferous needles, twigs.
Fa	14-8	Moist; black (10YR 2/2); strong, non-compact matted, resilient, fibrous; common, fine roots; few *Acarina;* common droppings; common fungal mycelia.
Hh	8-0	Moist; black (10YR 2/2); strong, non-compact matted, firm, fibrous; abundant, very fine roots; few *Acarina*, few *Myriapoda*; common droppings; common fungal mycelia.
Ah	0-20	Dark reddish brown (5YR 2.5/2 m); silt loam; moderate, fine to medium, granular; loose; plentiful, fine, vertical, inped roots; clear, wavy boundary; 10-25 cm thick.
ACg	20-40	Brown (7.5YR 4/3 m); sandy loam; weak, fine, granular; very friable; few, fine, horizontal, inped roots; clear, wavy boundary; 20-30 cm thick.
Cg	40+	Brown (10YR 4/4 m); sandy loam; weak, fine, granular; very friable; very few, medium, horizontal, inped roots. Water seepage at 75 cm.

Diagnostic Horizons and/or Properties.

Canadian System: Water table at 75 cm. Ah at least 10 cm thick overlying Cg horizon.	*Rego Humic Gleysol.*
U.S. Soil Taxonomy: Epipedon: Mollic Subsurface horizons: None. Subsurface materials: None.	*Oxyaquic Cryoboroll.*
Other Site Characteristics: Aquic moisture regime. Episaturation.	

Table 5.10 Pedon 11 (lower slope) - Selected physical and chemical properties of a Rego Humic Gleysol found north of the MMF.

HORIZON	Sand %	Clay %	Silt %	Texture Class	C %	N %	C/N	pH dH_2O	pH 0.01M $CaCl_2$
Ah	40.2	6.6	53.2	silt loam	3.1	0.23	14	6	5.4
ACg	80.7	2	17.3	loamy sand	3.5	0.25	14	6.3	5.6
Cg	74.4	2	23.6	loamy sand	3.9	0.28	14	6.5	5.7

HORIZON	Extractable Cations by NH_4OAc pH 7.0 (cmol(+)kg^{-1})								Base Sat.
	Al	Ca	Fe	K	Mg	Mn	Na	CEC	%
Ah	0.022#	16	0.011#	0.057	1.3	0.078	0.031	20	87
ACg	0.022#	6.5	0.011#	0.0050#	0.49	0.028	0.032	7.6	94
Cg	0.032	6.8	0.011#	0.16	0.5	0.010	0.009	6.8	saturated

HORIZON	Al_p %	Fe_p %	Al_o %	Fe_o %	ODOE*	Fe_p+Al_p	(Fe_p+Al_p) /clay	org C/Fe_p	$.5Fe_o+Al_o$
Ah	0.046	0.061	0.081	0.063	0.10	0.11	0.067	5.1	0.11
ACg	0.17	0.27	0.22	0.13	2.5	0.44	0.18	12	0.28
Cg	0.15	0.21	0.21	0.096	1.7	0.36	0.31	17	0.25

$_o$ = $(NH_4)_2C_2O_4$ $_p$ = $Na_4P_2O_7$ * = optical density of oxalate extract # = result lower than this detection limit

creations of Eutric Brunisols, Humo-Ferric Podzols, Ferro-Humic Podzols and Orthic Regosols from the same parent material.

Perhaps the most unique classification of the fifteen pedons is Pedon 11 (lower slope) being classified within the Soil Taxonomy's Mollisol Order. This pedon is not shown to meet the requirements for a Chernozemic A horizon due to its moisture regime not being drier than humid (Agriculture Canada Expert Committee on Soil Survey, 1987). This is not the case with the Soil Taxonomy classification as the Ah horizon meets the requirements of a mollic epipedon. This order is representative of grassland ecosystems and is not expected within a forested environment. If not for the epipedon, this pedon would have been classified within the Inceptisol Order along with the other Brunisols (Soil Survey Staff, 1994).

5.3 Nitrogen Concentrations and Age Class Analysis

Our results show distinct differences between the mineral horizons and the forest floor horizons; the forest floor horizons contain considerably higher levels of all forms of nitrogen studied. This is noted in other studies (such as Sveinbjörnsson *et al.*, 1995). Table 5.11 provides a summary of the mean values obtained for each of the sites. The complete data set from the nitrogen analyses is provided in Appendix D. The results of the Kruskal-Wallis H-Test Statistics and Fisher's LSD have been compiled in Table 5.12 and the results from the General Linear Model (GLM) are presented in Table 5.13. The results of these tests will be discussed separately in subsections 5.3.1 - 5.3.4.

Table 5.11 **Mean values of the results obtained from the nitrogen analyses for each study site. (A+B = mineral horizons; F.F. = forest floor horizons)**

Site	Total N (%)		NO_3^- (ppm)		NH_4^+ (ppm)		Min-N (ppm)		C/N Ratio	
	A+B	F.F.	A+B	F.F.	A+B	F.F.	A+B	F.F.	A+B	F.F.
1	0.127	1.81	2.31	8.38	6.65	117	39.6	1020	23.8	23.1
2	0.177	1.54	4.04	0.894	11.4	268	32.9	852	17.4	27.1
3	0.219	1.7	0.08	0.522	9.01	141	24.5	1160	16.7	20.7
4	0.152	1.62	1.08	0.467	14.2	97	30.5	1080	17.4	24
5	0.144	1.47	4.84	19	11.3	62.7	37.8	434	39.6	24.7
6	0.09	1.87	10.9	91.5	4.81	156	34.3	815	22.1	21.5
7	0.232	1.58	1.17	1.17	8.64	363	43.1	1270	14.5	23.9
8	0.136	1.87	15.3	18	11.2	287	56.7	1620	31.8	24.2
9	0.126	0.963	6.2	8.37	6.18	194	36.1	610	19.1	43.3
10	0.09	1.66	7.59	81.3	10.1	294	33.3	807	31.9	29.2
11	0.09	1.43	1.11	0.887	6.21	108	27.7	1110	18.4	24.3
12	0.138	1.57	0.1	0.4	7.33	94	30.1	728	15.5	25.9
13	0.162	2	8.98	108	4.33	43.9	37.8	520	21.8	19.2
Overall Mean	0.145	1.65	4.9	26.6	8.56	182	35.7	927	27.2	25.8

Table 5.12 **Kruskal-Wallis H-Tests and Fisher's LSD Tests for significant differences of the ranked mean nitrogen levels between age classes for each forest floor and mineral horizon using a 95% confidence interval.***

Horizon	Total N	Available NO_3^-	Available NH_4^+	Mineralizable N	C/N Ratio
L	H=1.30	H=9.55 E^a M^b L^b	H=6.08 E M $L^\#$	H=7.72 E M $L^\#$	H=3.19
F	H=0.380	H=9.83 E^a M^b L^c	H=0.630	H=3.55	H=4.95
H	H=1.51	H=9.74 E^a M^b L^b	H=3.23	H=11.1 E^a M^b L^b	H=3.74
A	H=2.70	H=4.59	H=9.22 E^a M^{ab} L^b	H=1.86	H=0.79
B	H=0.930	H=7.77 E^a M^b L^b	H=9.16 E^a M^a L^b	H=8.85 E^a M^b L^{ab}	H=6.75 E^a M^b L^b

* The critical test value with a df=2 is 5.99 (Griffith and Amrhein, 1991), beyond which a significant difference in the means of the ranked data is shown. Results have been adjusted for ties where required. E = Early Seral, M = Mid-Seral, L = Late Seral. No significant differences are found between age classes within the same cell which have the same superscripted.

While the H-Tests showed significant differences at a 95% confidence level, Fisher's LSD did not. Since Fisher's LSD is designed conservatively and the H-Test results are not far above the critical value, these results will be treated as not being significantly different (B. Zumbo, personal communication, 1997).

Table 5.13 **Results of the General Linear Model examining the interaction effect between soil horizons and age classes using a 95% confidence interval.***

N Type	df	Seq. SS	Adj. SS	Adj. MS	F
Total N	8, 173	14024	14024	1753	2.82
Avail. NO_3^-	8, 173	47457	47457	5932	3.34
Avail. NH_4^+	8, 173	6105	6105	763	1.21
Min. N	8, 173	24275	24275	3034	4.71
C/N Ratio	8, 173	25887	25887	3236	1.35

* The critical test value with a df=(8, 173) is 2.03 (Griffith and Amrhein, 1991), beyond which a significant difference in the means of the ranked data is shown.

5.3.1 Total N

The minimum mean value obtained for total N within the mineral horizons (combined A and B horizons) was 0.0900% and 0.232% was the maximum value (Table 5.11). For the forest floor horizons (combined L, F and H horizons), the minimum and maximum means were 0.963% and 2.00%, respectively. Our results have a slightly smaller range than the findings of Klinka *et al.* (1994) in the dry and cold (SBSdk) and the moist and cold (SBSmc) Sub-boreal Spruce biogeoclimatic subzones, but are comparable to those of Taylor *et al.* (1991) who conducted prescribed fire and mechanical site preparation studies on different sites within the moist and cool (SBSmk) biogeoclimatic subzone of the Sub-boreal Spruce zone. Since their sites had been logged in 1968, their results are comparable to our Early Seral site results. Our results are much closer to their findings for the mineral horizons, though this is not the case for the forest floor horizons. While they also examined mesic sites, their dominant vegetation was within the hybrid spruce-oak fern site series. This variation in vegetation, as well as the drier climate compared to our sites, may account for the differences between the two studies. In the SBS near Prince Rupert, Macadam (1987) recorded similar forest floor horizon values, but total N values for the mineral horizons are much lower than our findings. In their study northeast of Prince George, Kimmins and Hawkes (1978) recorded total N values very similar to our grand mean total N value of 1.65% for our forest floor samples.

Table 5.14 provides the total N concentrations (pooled values) for each of the horizons by age class. As determined by the Kruskal-Wallis H-Tests (Table 5.12), there is no significant difference between the ranks of the means for each of the different age classes for the L, F, H, A and B horizons. This could indicate that the levels of total N are no longer affected by the fire event after

Table 5.14 Minimum, maximum, mean and standard deviations of Total N contents (%) by horizon and age class.

Horizon	Age Class	n	Minimum	Maximum	Mean	Standard Deviation
L	Early Seral	7	0.735	2.21	1.59	0.664
	Mid-Seral	13	0.534	2.27	1.56	0.478
	Late Seral	9	1.24	1.81	1.52	0.193
F	Early Seral	5	0.446	2.31	1.68	0.729
	Mid-Seral	11	1.13	2.62	1.84	0.379
	Late Seral	7	1.6	1.91	1.72	0.0966
H	Early Seral	10	0.726	2.05	1.5	0.397
	Mid-Seral	11	1.36	2.34	1.78	0.35
	Late Seral	11	1.1	2.41	1.63	0.322
A	Early Seral	16	0.012	0.258	0.114	0.0726
	Mid-Seral	20	0.04	0.29	0.099	0.0629
	Late Seral	16	0.005	0.314	0.13	0.0729
B	Early Seral	16	0.086	0.356	0.148	0.0647
	Mid-Seral	20	0.067	0.593	0.205	0.139
	Late Seral	16	0.042	0.323	0.172	0.077

14 years (assuming that prefire levels are equivalent to the Late Seral levels). As noted in Chapter 3, one-third of the total N content of the SBS can be found within 30 cm of the forest floor (Macadam, 1987). Since no significant differences in total N are found in the forest floor or A and B horizons, this is a good indication that changes in total N concentrations during a fire event may be returned to pre-fire levels within a 14-year period following the event in the SBSvk1. This is in agreement with published findings as the replacement of the total N to prefire levels has been shown to occur from within a few months after the fire in Mediterranean-type environments (Kutiel and

Naveh, 1987) to a few years in some fir ecosystems in the American Pacific Northwest (Wells *et al.*, 1979). Unfortunately, regional data with which to compare our results examining the changes of nitrogen concentrations over time following wildfire is lacking; most of the studies in this region have looked at post-fire conditions after logging and slash burning.

Sampling procedures have been shown to affect post-fire total N results (Mroz *et al.*, 1980). They found that their top forest floor layers had sustained significant total N losses immediately after the fire, however, their lower forest floor horizons showed increases in total N (Mroz *et al.*, 1980). When the entire forest floor was examined, their statistical results are similar to ours in that they found no significant difference between the prefire and post-fire total N levels. They noted that studies that examined only the ash material following a forest fire would overestimate the losses of total N which is not the case in our study. This procedural dichotomy does not affect our results as the L, F and H horizons were all examined.

In examining the GLM for the ranked total N data using the results of the age class analysis, a significant difference is found in the interaction effect between the forest age classes and the soil horizons. Further examination will be required to determine the factor(s) influencing this interaction. In their study, Reich *et al.* (1997) showed that soil type/parent material explained much of the variation in annual N mineralization. Since our sites were found on different soil types (Table 5.2) and on different types of parent material (Table 2.1), these differences might provide more information on the N transformations within the MMF, however, this requires further study which is not within the scope of this thesis.

5.3.2 Available NO_3^- and NH_4^+

Our mean available NO_3^- levels range from 0.0769 - 15.3 ppm in the mineral horizons and from 0.400 - 108 ppm in the forest floor (see Table 5.11). The available NH_4^+ ranges from 4.33 - 14.2 ppm and 43.9 - 363 ppm in the mineral and forest floor horizons, respectively. Taylor *et al.* (1991) reported NO_3^- values between 1.0 - 1.4 ppm in their mineral horizon samples which are much lower than the majority of our mean values, particularly when compared to our Early Seral sites which range from 4.84 - 10.9 ppm. Their 20-year-old site has more in common with our Mid-Seral sites (four of our five sites have NO_3^- levels between 0.077 ppm and 2.31 ppm). Forest floor findings reveal similarities between four of our sites and the sites studied by Taylor *et al.* (1991), however, the majority of our sites have much higher values.

The data obtained for the available NO_3^- and NH_4^+ (pooled by age class) are summarized in Tables 5.15 and 5.16, respectively. It should be noted that these results are based on single point measurements and represent a snapshot of the nitrogen dynamics in the sub-boreal forest. Recently, concern has been raised that single point data may not be representative of NO_3^- levels in coniferous forests as nitrification (oxidation of NH_4^+ to NO_3^-) from microbial activity is believed to be occurring at a rate faster than can be measured, thus revealing available nitrogen levels much lower than may actually be the case (Stark and Hart, 1997). However, our procedure reports the total amount of available NO_3^- in the collected soil samples and does not infer rates of turnover. If NO_3^- is locked in microbial biomass, it still is unavailable to plants and does not undermine this research. It is believed that this new paradigm of nitrogen retention in forest soils be examine with respect to northern ecosystems.

Table 5.15 Minimum, maximum, mean and standard deviations of available NO_3^- contents (ppm) by horizon and age class.

Horizon	Age Class	n	Minimum	Maximum	Mean	Standard Deviation
L*	Early Seral	7	1.4	181	68.5	65.3
	Mid-Seral	13	0.005	165	23.5	47.9
	Late Seral	9	0.2	3.7	1.14	1.23
F*	Early Seral	5	2.6	119	69.4	48.6
	Mid-Seral	11	0.005	164	27.7	52.1
	Late Seral	7	0.005	1.5	0.721	0.605
H*	Early Seral	10	0.5	209	50.4	65.6
	Mid-Seral	11	0.005	111	18.5	34.9
	Late Seral	11	0.005	67	6.45	20.1
A	Early Seral	16	0.005	13.6	5.26	5.51
	Mid-Seral	20	0.005	12.2	1.24	2.95
	Late Seral	16	0.005	9.05	2.88	3
B*	Early Seral	16	0.005	22	10.2	5.71
	Mid-Seral	20	0.005	11.8	3.66	3.82
	Late Seral	16	0.005	27.6	7.39	10.1

* = H-Tests showed significant differences between the age classes.

By Kruskal-Wallis analysis, the A horizon is the only one which is found not to have a significant difference between the ranked means of the NO_3^- values. In each of the other horizons, the Early Seral age classes are grouped separately from the Mid-Seral and Late Seral. Results for the forest floor show decreasing NO_3^- levels from the Early Seral through the later seral age classes. Increased nitrification rates during and following the forest fires could be responsible for these increased levels in the Early Seral stage. Similar results were reported by Viro (1974) who found increased NO_3^- levels (up to three times the control levels) for six years following a fire in a Fenno-

Table 5.16 Minimum, maximum, mean and standard deviations of available NH_4^+ contents (ppm) by horizon and age class.

Horizon	Age Class	n	Minimum	Maximum	Mean	Standard Deviation
L*	Early Seral	7	39.3	391	189	137
	Mid-Seral	13	23.3	538	234	176
	Late Seral	9	34	347	168	107
F	Early Seral	5	41.5	133	71.4	41.2
	Mid-Seral	11	89.7	553	255	177
	Late Seral	7	66	538	226	202
H	Early Seral	10	23.2	318	95.7	108
	Mid-Seral	11	26.7	514	170	146
	Late Seral	11	35.8	647	164	177
A*	Early Seral	16	1.95	25.3	8.06	5.75
	Mid-Seral	20	4.55	19.5	10	4.16
	Late Seral	16	3.9	24.3	13.4	6.1
B*	Early Seral	16	1.4	13.5	5.23	3.37
	Mid-Seral	20	1.65	9.75	6.23	2.39
	Late Seral	16	2	15.3	8.71	3.54

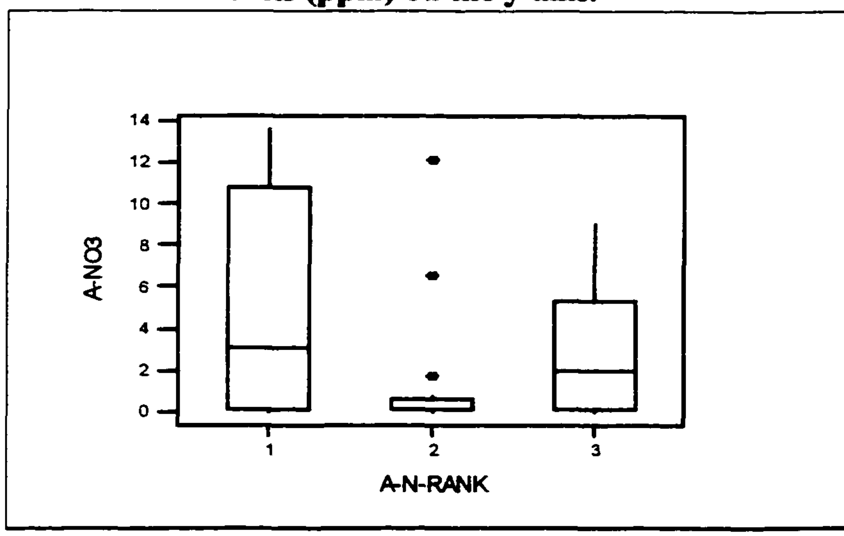
* = H-Tests showed significant differences between the age classes.

Scandian spruce forest dominated by podzolic soils. It is well documented that the removal of overlying vegetation following a forest fire will increase soil temperatures, pH and the availability of cations resulting in higher rates of decomposition and mineralization (Feller, 1982; MacLean *et al.*, 1983; Wells *et al.*, 1979). Microbial biomass has been shown to be a major source of mineralized nitrogen following surface heating. The higher temperatures that may result from the removal of the duff layer can lead to increased microbial activity which, in turn, can lead to an increased rate of mineralization (Andison, 1994). This "assart effect" continues until the increased nutrients are taken up by new plants, are immobilized by microbes or are used up in chemical reactions (Kimmins, 1997).

On a site by site basis, four of our sites (Sites 6, 8, 9 and 13) have higher mean levels of NO_3^- than NH_4^+ in the mineral horizons; the remainder of the sites have more NH_4^+ than NO_3^-. Site 13 shows similar results in the forest floor horizons. These sites are within the Early Seral age class(with the exception of Site 8 which is Late Seral). Viro (1974) found that NH_4^+ levels can be 20 times higher than NO_3^- in the humus layer of acidic Fenno-Scandian spruce forests. However, Viro (1974) also noted that NH_4^+ levels dropped sharply during the first three years following a fire, not significantly increasing until after 12 years and not showing pre-fire levels until 50 years following the fire.

Even though the mean NO_3^- level for the A horizon of the Early Seral sites is five times that of the Mid-Seral sites and almost double that of the Late Seral, no statistical significance could be demonstrated. A closer examination of the NO_3^- data using a boxplot (Figure 5.5) shows the range for the A horizon and indicates that the small sample size may be the major determinant of the non-significance. The even spread of the outliers in the Mid-Seral age class may be causing the Kruskal-Wallis test statistic to accept the ranked data as being equally distributed. This may occur because an alternation between the age classes of the ranked data gives the appearance that the data is more thoroughly distributed than is actually the case. The Early Seral sites tend to have thicker H horizons than the older sites, however, the variation in the depths of the forest floors between the different horizons is not statistically significant (from Kruskal-Wallis analysis of the depths of each of the forest floor horizons based on age class). In theory, thicker forest floor horizons should yield more decomposing materials derived from the herbaceous and mossy plants found predominantly at the younger sites although this can only be verified if further analysis of the decay rates of these plants is done.

Figure 5.5 Boxplot of the A horizon NO_3^- levels with the Early Seral (1), Mid-Seral (2) and Late Seral (3) age classes on the x-axis and the NO_3^- levels (ppm) on the y-axis.



Results indicate that Site 6, the Gleyed Eluviated Dystric Brunisol, has some of the highest NO_3^- levels (A horizon = 5.75-12.4 ppm, B horizon = 9.55-14.1 ppm) of our sites. Since NO_3^- is negatively charged, leaching in groundwater may be seen as a natural sink which may be hindered at this location. Courtin *et al.* (1988) noted that laterally moving groundwater may actually act as a source of available nutrients in a soil as they are being transferred within the system and not being lost from it. This appears to have been the case at this study site. This increased nutrient availability may be beneficial to plants tolerant of high water levels such as *Epilobium angustifolium* (55% cover at Site 6) as well as the few *Abies lasiocarpa* and *Picea glauca x engelmannii* seedlings which are found at the site (MacKinnon *et al.*, 1992).

The null hypotheses were rejected for the GLM for the ranked NO_3^-. The differences shown by the age effect were previously presented in the Kruskal-Wallis tests, however, this model confounds the analysis by indicating that age alone may not explain the differences between the NO_3^- levels found in the different forest age classes. When the NO_3^- levels are ranked for the mineral horizons alone, then subjected to the same GLM as above, the results indicate that there is no significant difference between the different age classes. However, this result may be spurious due to the high p value (0.442). This may be an indication that the observed variation in NO_3^- levels is occurring in the forest floor horizons and is large enough to override the lack of variation shown in the mineral horizons given that the NO_3^- levels of the forest floor can be as much as 10 times higher than the mineral horizons. The analysis of the ranked NO_3^- for only forest floor horizons indicates a significant difference between the age classes, however, there is no significant difference between the horizons and the interaction effect between the age classes and horizons as the p values are 0.579 and 0.973, respectively.

Available NH_4^+ levels are highest in the Mid-Seral age class for the forest floor samples and highest in the Late Seral age class for the mineral soil horizons. Significant differences are found between the ranked means of available NH_4^+ in the A, B and L horizons. Different trends are noted for the forest floor and mineral horizons. In the forest floor horizons, the NH_4^+ values are lowest in the Early Seral, highest in the Mid-Seral and intermediate in the Late Seral compared to an overall increase with time since the fire disturbance in the mineral horizons.

While the H-Test for the L horizon does show a significant difference, this is not revealed by the LSD post-hoc test. Examination of the test values show that the H-Test result for this horizon is slightly over the 95% confidence level (see Table 5.12). Since a marginal increase in the level of probability would remove the significant difference and since Fisher's test does not show a difference, the significance was ignored (B. Zumbo, personal communication, 1997).

In both the A and B horizons, the Early Seral age classes are grouped with the Mid-Seral age classes by Fisher's test. In the A horizon, the Mid-Seral age class is not shown to be significantly different from the Late Seral age class. This indicates a steady increase in NH_4^+ levels over time in the mineral horizons. This may be due to the decrease in the nitrification rate, though it is difficult to confirm the statement based on single extractions and because of the paucity of data on microbial activity (Stark and Hart, 1997). As the canopy trees grow and create more shade, lower soil temperatures are to be expected due to diminished insolation.

The GLM analysis of the interactions between forest age classes and soil horizons for the NH_4^+ show significant differences between the ages and the horizons, however an interaction effect is not seen (Table 5.13).

5.3.3 Mineralizable N

Mineralizable N represents the organically bound nitrogen in the soil which can be rendered available to plants. Our mean values for mineralizable N range between 24.5 ppm and 56.7 ppm in the mineral horizons and between 434 ppm and 1620 ppm in the forest floor horizons (Table 5.11) which are consistent with values from unpublished studies in the SBS in this area (P. Sanborn, personal communication, 1997). Our values are much higher than those in the drier SBS subzones studied by Klinka *et al.* (1994) in which mean levels of 0.8 - 181 ppm and 187 - 310 ppm were reported for the mineral and forest floor horizons , respectively. Forest floor mean values from white spruce forests in interior Alaska were much lower being listed between 16 - 32 ppm for young sites (< 3 years following logging) and 19 ppm for a 110 year old site (Gordon and Van Cleve, 1983). Fyles *et al.* (1990) determined forest floor potential mineralizable N values between 152 - 847 ppm in the dry, maritime Coastal Western Hemlock biogeoclimatic zone; half of our values fall within this range, though the remainder of our values are higher. Results from studies in a Mountain Hemlock forest in Oregon (Matson and Boone, 1984) have shown results of 91 ppm (< 10 years), 54 ppm (18 - 50 years), 35 ppm (65 - 90 years) and 32 ppm (>200 years) for the forest floor horizons and 1.2 ppm (< 10 years), 1.5 ppm (18 - 50 years), 0.9 ppm (65 - 90 years) and 0.4 ppm (>200 years) for the mineral horizons which are all greatly below our results. It is important to note that the laboratory procedure we used (Powers, 1980) represents potential mineralization and may not reflect field availability. Mineralization may be overestimated because the sample preparation process includes the removal of carbon in the form of plant materials larger than 2 mm diameter, the C/N ratio is decreased thereby increasing the activities of soil microorganisms (Zak *et al.*, 1986).

The breakdown of data into age classes (Table 5.17) indicate significant differences between the ranked means of the L, H and B horizons. In each of these cases, the Mid-Seral and Late Seral age classes are not significantly different from each other. The Early Seral age class is grouped with the Late Seral in the B horizon but not in the H horizon. As with the L horizon in the NH_4^+ analysis, the H-Test notes statistically significant differences, while Fisher's LSD test does not. As indicated previously, this discrepancy is ignored and no significant difference is assumed (B. Zumbo, personal communication, 1997).

Table 5.17 Minimum, maximum, mean and standard deviations of mineralizable N contents (ppm) by horizon and age class.

Horizon	Age Class	n	Minimum	Maximum	Mean	Standard Deviation
L*	Early Seral	7	462	1080	676	249
	Mid-Seral	13	574	2040	1040	407
	Late Seral	9	434	1640	938	465
F	Early Seral	5	378	966	610	246
	Mid-Seral	11	616	1710	1214	371
	Late Seral	7	560	1230	906	275
H*	Early Seral	10	308	1150	550	261
	Mid-Seral	11	616	1390	1020	283
	Late Seral	11	476	1860	1060	495
A	Early Seral	16	16.8	53.2	28	11
	Mid-Seral	20	19.6	146	37	27
	Late Seral	16	16.8	47.6	31	8.6
B*	Early Seral	16	25.2	64.4	45	11
	Mid-Seral	20	14	61.6	31	12
	Late Seral	16	11.2	84	44	24

* = H-Tests showed significant differences between the age classes.

The mineralizable N tests are vital as they are believed to represent a significant nitrogen pool within the ecosystems (Fyles *et al.*, 1990). The anaerobic method used approximates the potential mineralization of nitrogen over a six-month period in the field (Powers, 1980). While it has been noted that nutrient cycling within ecosystems may change with succession (MacLean *et al.*, 1983), relatively small changes should be seen in nitrogen mineralization in forest floors during secondary succession after disturbances like fire (versus logging) (Vitousek *et al.*, 1989). Our results in the L and H layers, from stands originating after fire, tend to follow their trend. The Kruskal-Wallis H-

Tests found significant differences in the ranked means for both of these horizons, though not for the F horizon. Examination of the descriptive data indicates that the Early Seral mineralizable N levels are significantly lower than the Mid-Seral and Late Seral age classes. The L horizon values are 676 ppm in the Early Seral age class and 1040 ppm and 938 ppm in the Mid-Seral and Late Seral classes, respectively. Similarly, in the H horizons, the Early Seral mean is almost doubled from 550 ppm to 1020 ppm in the Mid-Seral age class and 1060 ppm in the Late Seral.

The interaction effect between the different horizons and the age classes shown in the GLM (Table 5.13) indicates that there is another variable affecting the mineralizable N levels. As with above, further analysis would be required to determine the cause.

The high levels obtained for mineralizable N may be attributed to the low soil temperatures determined for all of the study sites. Mean annual soil temperatures under 10°C have been found to limit nutrient mineralization at the forest limit in the interior of Alaska (Sveinbjörnsson *et al.*, 1995) and in the Scottish Highlands (Morecroft *et al.*, 1992). The annual soil temperatures reported in our study are lower than 10°C. It appears that low soil temperatures may be slowing the decomposition of the organic litter and, therefore, maintaining the unusually high mineralizable N levels (MacLean *et al.*, 1983; Reich *et al.*, 1997).

5.3.3.1 Mineralizable N and Site Quality

Mineralizable nitrogen has been used as an index of forest site productivity (Klinka *et al.*, 1994). The humus form acts as an expression of soil biological activity and the nature of the forest floor may be viewed as an indicator of decomposition and the potential release of available nutrients (Courtin *et al.*, 1988). Fyles *et al.* (1990) have indicated that forest floors of similar morphology should show similar nitrogen mineralization characteristics. While the range is larger for our H horizons, the mean and median are higher for the F horizons (Table 5.18) indicating an overall higher level of potentially available nitrogen within the F horizons of the study sites. This result mirrors the amount of F and H materials found within the pedons studied. Though not all pedons had F and H horizons (10 pedons contain an F horizon and 10 pedons contained H horizons), total depths of these two horizons were nearly equal when compared.

Table 5.18 Comparison of mineralizable N results between the F and H horizons.

Horizon	Min. (ppm)	Max. (ppm)	Mean (ppm)	Median (ppm)
F	378	1708	989	966
H	308	1862	889	847

Klinka *et al.* (1994) have suggested that mineralizable nitrogen levels within the top 30 cm of the mineral soil may be used as an estimate of the nutrient conditions in montane boreal forests. Each of the sites has been classified (Table 5.19) using the procedure proposed by Klinka *et al.* (1994) for the characterization of the quality of the nutrient regimes based on mineralizable N levels in the mineral horizons (<2 ppm = very poor, 2-8.9 ppm = poor, 9-27.4 ppm = medium, 27.5-110 ppm = rich, and >110 ppm = very rich). A weighted average based on the determined depths of the A and B composite samples is being used as an approximate representation of the top 30 cm of the mineral soil (K. Klinka, personal communication, 1996). Each of the age classes are within the lower range of the rich soil nutrient regime classification (Early Seral mean = 34.6 ppm, Mid-Seral mean = 34.2 ppm, Late Seral mean = 34.1 ppm). However, when compared on a site by site basis, sites 3, 4, and 11 are within the medium soil nutrient regime while the 10 other sites remain within the rich soil nutrient regime. Klinka *et al.* (1994) found the majority of their sites to be in the medium and poor categories, though they conducted their study in drier and warmer subzones (their SBSdk and SBSmc versus our SBSvk) of the Sub-boreal Spruce biogeoclimatic zone. As well, their studies were conducted primarily on Luvisols and less frequently on Podzols or Brunisols, whereas, the majority of our pedons are Orthic Humo-Ferric Podzols and Eluviated Dystric Brunisols while only two are Luvisols. However, their findings for the very moist sites ranged from medium to very rich which was closer to our findings in a very wet SBS subzone.

Table 5.19 Mean mineralizable N per site as a weighted composite of the A and B horizon results.

Site	Classification	Mean Mineralizable N (ppm)	Soil Nutrient Regime
1	E.DYB	41.1	rich
2	O.HFP	30.1	rich
3	E.DYB	23.8	medium
4	E.DYB	25.2	medium
5	O.GL	38.2	rich
6	GLE.DYB	30.1	rich
7	O.HFP	45.1	rich
8	O.HFP	50.7	rich
9	O.HFP	40.5	rich
10	GLE.DYB	32.7	rich
11	E.DYB	27.4	medium
12	E.DYB	30.2	rich
13	O.HFP	29.4	rich

When the weighted average mineralizable N levels (Table 5.19) are examined with respect to the soil classifications, the pedons classified as Orthic Humo-Ferric Podzols are shown to have three of the top four weighted mean values. Pedons 7, 8 and 9 all have values above 40 ppm, yet all three come from different age classes. It is possible that the translocation of amorphous organic matter in the podzolization process and high levels of precipitation in our study area may be responsible for this trend, though this is only conjecture and requires further study. As the organic matter moves downward through the sandy soils, nitrogen immobilized in the humus may not be released, thus leading to increased mineralizable N levels. This is contrary to the findings of Reich *et al.* (1997) who indicated that Luvisols should have higher mineralizable N levels due to their better water-holding capacity and higher base saturation levels. However, they felt that water shortage was limiting in their Brunisols which probably is not the case in the SBSvk. In fact, the opposite may be true in our study region as water saturation of the soil during the spring thaw is more likely to be a problem in clayey soils which drain more slowly than sandy soils.

5.3.4 C/N Ratio

The C/N ratio is used as an indicator of the propensity of nitrogen to be mobilized with the tendency increasing as the ratio decreases (Viro, 1974). In our study, the mean C/N ratio values for the forest floor horizons range from 19.2 to 43.3 and from 14.5 to 39.6 for the mineral horizons. Our mean values have a larger range than those reported by Klinka *et al.* (1994) who reported C/N ratios from 27 to 40 in the forest floor and 19 to 20 in mineral horizons of other subzones of the SBS, though their sites (SBSdk and SBSmc) are drier than ours occurring on the Interior Plateau rather than in mountainous terrain. However, our results are similar to those of Kimmins and Hawkes

(1978) who reported a mean value of 23.2 for their forest floor samples and means of 9.9 and 20.9 for their Ae and Bfl horizons, respectively, in the SBSwk subzone northeast of Prince George.

Our C/N values are substantially lower than those of the decaying wood dominated forest floor sites in the Coastal Western Hemlock (CWH) biogeoclimatic zone studied by Fyles *et al.* (1991b) in which they obtained ratios between 215 and 344. One should note that Fyles *et al.* (1991b) assumed a 50% C content whereas our C content ranged from 28% to 47%. However, it is not unusual for SBS subzones in the interior of British Columbia to have lower C/N ratio values as these areas are drier (mean annual precipitation for SBS zone ranges from 440 - 900 mm) than the CWH (mean annual precipitation ranges from 1000 - 4400 mm) regions (Pojar *et al.*, 1991; Meidinger *et al.*, 1991). The mineral horizon values are slightly higher than those obtained by Fisk and Schmidt (1995) in their *Carex* tundra communities in the Front Range of the Colorado Rockies (mean C/N Ratio values of 12.1 - 13.0). Theoretically, the higher ratios in our region compared to those presented in the other studies above are to be expected as the cooler temperatures of our study area lead to slower rates of decomposition (Brady, 1990).

The results of our C/N ratio analysis are provided in Table 5.20. Only the B horizon shows a significant difference in the C/N ratio. In the B horizon, the Mid-Seral and Late Seral age classes are grouped separately from the Early Seral age class based on Fisher's LSD. Since the C/N ratio is considered to be somewhat constant (the length of time for recovery following the addition of new materials being determined by the C/N ratios of the substances added) within ecosystems, it is expected that no significant differences will be observed (Brady, 1990). Macadam (1987) found that C/N ratios returned to prefire levels within 21 months of broadcast slash burning in the SBS zone which is a shorter period of time than had occurred prior to the sampling of our youngest site (Site

13 at 3 years post-fire).

Table 5.20 Minimum, maximum, mean and standard deviations of C/N ratio by horizon and age class.

Horizon	Age Class	n	Minimum	Maximum	Mean	Standard Deviation
L	Early Seral	7	18.2	52.1	26.4	11.7
	Mid-Seral	13	18.9	75	29.1	14.5
	Late Seral	9	21.3	35	27.3	3.64
F	Early Seral	5	18.1	99.3	35.7	35.6
	Mid-Seral	11	16.9	25.3	21.8	2.73
	Late Seral	7	21	28.4	25.1	2.82
H	Early Seral	10	16.9	53.6	25.5	10.4
	Mid-Seral	11	17.4	25.6	21.6	2.72
	Late Seral	11	19	29	24.6	3.42
A	Early Seral	16	4.05	169	30	37.5
	Mid-Seral	20	11.4	64.9	24.6	14.1
	Late Seral	16	7.93	503.2	52.2	121
B*	Early Seral	16	9.61	38	21.4	5.68
	Mid-Seral	20	8.04	29.5	17.5	6.29
	Late Seral	16	10.9	64.8	20.3	12.5

* = H-Tests showed significant differences between the age classes.

Net immobilization of nitrogen has been determined to occur in forest floors with C/N ratio values above 25 and total N values below 1.8% (Haynes, 1986b). The mean values of five of our sites fall within these ranges; sites 2, 5, 9, 10, 12 (see Table 5.11). The remainder have C/N ratio values below 25. No trend could be determined with respect to the age class analysis.

5.3.5 Nitrogen and Vegetation Coverage

Nitrogen mineralization has been found to be strongly related to the species composition of an ecosystem primarily due to the differences in the chemical quality of the plant litter (Zak *et al.*, 1986). Vitousek *et al.* (1989) suggested that available nitrogen may not be limiting to plants during primary succession since many of these plants have non-sclerophyllous leaves (i.e. hardwoods) and may be able to obtain sufficient nitrogen from precipitation. Our findings indicate that herbs and mosses are most abundant in the Early Seral age class. Mosses are known to decompose slowly and act as a water filter and nutrient sink by absorbing precipitation efficiently (Vitousek *et al.*, 1989). A thick moss layer also has the ability to lower soil pH and temperature which may lead to slower organic matter decomposition and lower nutrient availability (Bissett and Parkinson, 1980; Kuuluvainen *et al.*, 1993). Differences in cellulose, hemicellulose and lignin composition between the coniferous needles and herbaceous understory would also lead to a different rate of decomposition over time as the slower decomposing needles gradually increased in percentage in the forest floor horizons (Vitousek *et al.*, 1989). As noted by Fyles *et al.* (1990), an understanding of the mineralization characteristics of the different forest floors, and indeed, the different plants providing materials for the forest floors, is required before accurate predictions of the amount of nitrogen available to plants can be made.

Expected successional effects would be a larger take-up and storage of nutrients by the growing trees as well as a possible decrease in the leaching of nutrients into the soil due to the concentrating of precipitation down the tree stems rather than evenly over an unprotected area. Also, the addition of coniferous needles to the forest floor would increase the acidity and affect the composition of the litter as well as the F and H layers (Kuuluvainen *et al.*, 1993). It has also been suggested that white spruce forests will revert to white spruce forests following moderate burning and will change to aspen, birch, poplar or spruce following single severe fires (Kelsall *et al.*, 1979). Repeated severe fires change the forests to herbaceous or shrubby communities (Kelsall *et al.*, 1979). Our Early Seral sites are dominated by herbs and shrubs, though spruce seedlings have been listed in the inventory for this age class. Deciduous tree cover does not appear to play a large role in early post-fire succession in the SBSvk subzone (C. Delong, personal communication, 1997).

A major source of NH_4^+ in forest soils comes from the decomposition of amino acids, amides and proteins from dead plants, animals and microorganisms (Haynes, 1986a). It appears that the increased cycling of the growing vegetation cover may be responsible for the noted higher concentrations of NH_4^+ over time.

Table 2.2 provides a breakdown of the available vegetation cover for Sites 1-12 by species and age class and the mean amount of each type of vegetation is summarized in Table 5.21. (Note: Where vegetation coverage exceeds 100% in the herb coverage, plants are overlapping.) The species averaging more than 10% coverage in the Early Seral sites are *Rubus parviflorus*, *Epilobium angustifolium*, *Gymnocarpium dryopteris* and *Polytrichum juniperinum*. In the Mid-Seral sites, *Picea glauca x engelmannii*, *Oplopanax horridus*, *Vaccinium membranaceum* and *Vaccinium ovalifolium* represent at least 10% mean percent coverage. The Late Seral sites species representing at least 10% coverage, include *Abies lasiocarpa*, *Picea glauca x engelmannii*, *Oplopanax horridus*, *Dryopteris assimilis* and *Gymnocarpium dryopteris*. Data reveal a steady increase in the percent coverage of *Abies lasiocarpa* and *Picea glauca x engelmannii* from the Early Seral through the Mid- and Late Seral age classes: from the maximum of 1% cover at one of the sites in the Early Seral to the 60% maximum seen in the Mid-Seral and the 84% in the Late Seral.

Table 5.21 Mean percent vegetation coverage by plant type and forest age class.

Age Class	Tree Cover %	Shrub Cover %	Herb Cover %	Moss Cover %
Early Seral	0.4	52.6	108.9	35.3
Mid-Seral	32.4	83.5	54.5	19.1
Late Seral	56.8	75.1	72.8	33.9

Epilobium angustifolium, a nitrophytic species representative of nitrogen-rich soils (Klinka *et al.*, 1989), is found predominantly in the Early Seral sites. However, other species such as *Rhododendron albiflorum* (indicative of nitrogen-poor sites) and *Calamagrostis rubescens* (indicative of medium nitrogen levels) also are found only on the Early Seral sites. Robertson *et al.* (1988) examined the spatial variability of nutrients (particularly nitrogen) and plant succession resulting from a natural disturbance. Their study looked at the small-scale heterogeneity of nutrient regimes as related to the pattern of early plant succession. They noted that it was unclear if the plant community reflected the nutrient levels or whether they affected them. Also, though it was originally believed that *Epilobium angustifolium* and *Rubus idaeus* occurred on recently burned sites because they required nitrogen in the NO_3^- form, *Epilobium angustifolium* has also been shown to be able to take up nitrogen as NH_4^+ (Viro, 1974). Nevertheless, the variety of plants inventoried within the study sites may cause the variation noted in the different nitrogen levels within the Early Seral communities (as is demonstrated with the NO_3^- results in Figure 5.5).

Higher mean mineralizable N levels are found in the Mid-Seral and Late Seral age classes than in the Early Seral age class (Table 5.17). In his study in Quebec, Moore (1980) found that the litter from spruce trees had the ability to immobilize nitrogen. Since the sites with more spruce trees would be more likely to have spruce litter within the forest floor horizons, and since conifer needles are among the slowest of forest floor materials to decompose (Bissett and Parkinson, 1980), this may be a factor which explains the variation in mineralizable N levels over time. Also, mosses such as *Pleurozium schreberi* (inventoried in the Mid-Seral and Late Seral), *Hylocomium splendens* (only in the Late Seral) and other feather mosses have been found to act as nitrogen immobilizers (Weber and Van Cleve, 1981) and may add to the higher mineralizable N values found in these age classes. As well, ericaceous shrubs such as the *Vaccinium* species are known for their suppression of nitrogen mineralization (Kimmins, 1996) and *V. membranaceum* and *V. ovalifolium* were found predominantly in the Mid-Seral and Late Seral sites which may add to the explanation of the higher levels of mineralizable N found there.

Arocena *et al.* (in preparation, 1997), using the data from this study, estimated the total mass of the different forms of nitrogen which increased with stand age. However, the increase in content does not necessarily reflect nitrogen availability which is related to nitrogen concentration and the rate at which nutrients are released through decomposition and mineralization (Keenan *et al.*, 1993). Nitrophytic species indicative of nitrogen rich sites such as Devil's Club (*Oplopanax horridus*) (Klinka *et al.*, 1989) demonstrate the trend by showing an increase in percent coverage from an average of 0.3% in the Early Seral sites to an average of 19% in the Mid-Seral sites and 43% per site in the Late Seral sites.

It should be noted that the intensity of the fires upon which this retrospective study is based were not known, although rough estimates of forest floor indicates a minimum of 50% reduction in depth after wildfires. More intense fires may lead to higher soil temperatures and longer duration of soil heating, which, in turn, can affect the length of time for mycorrhizae-dependent plants to return to the sites (Klopatek *et al.*, 1988). Thus, the intensity of the forest fire may have acted as an additional confounding factor affecting the species compositions observed and is another reason this study has not attempted to link specific plants to the nitrogen activity of the sub-boreal forest.

Since the purpose of this thesis is to examine the relationships between post-fire stand age and nitrogen dynamics, the area of plant/nutrient regime interactions was not investigated and would require considerable effort to determine if any relationships exist.

5.3.6 Projection of Nitrogen Concentrations within the MMF

Nine combinations of soil complexes and forest age classes representative of our study sites are found to overlap in significant quantities within the SBSvk biogeoclimatic subzone of the MMF during GIS analysis; sufficient data exists to project nitrogen values for six of these as soil samples were not collected in areas matching the remaining three soil complexes/age classes coverages. The combined area of these six complexes represents approximately 10% of the total area of the model forest (Table 5.22). The projections of nitrogen levels are provided in map form as Figure 5.6. (*Note*: Only the northwest section of the model forest is presented in this map as the concentration of polygons in this region allow the most confidence in making predictions.)

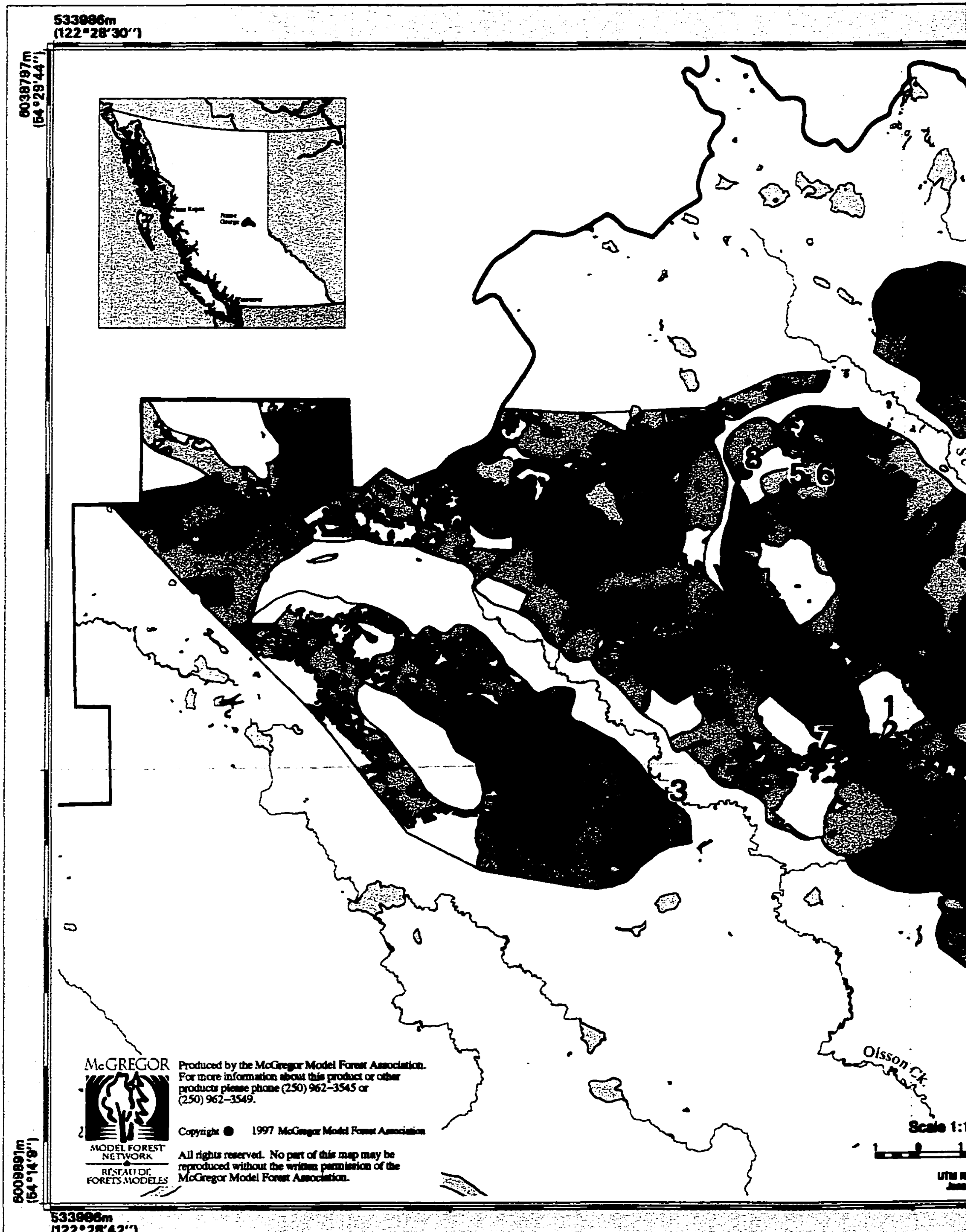
It is intended that the projections made herein be used in conjunction with other GIS layers in order to obtain a more complete picture of the landscape. Use of the GIS database in this manner may provide forest practitioners with a tool which may be included in the monitoring of tree plantations, however, it is advised that nitrogen levels be monitored over time to confirm the ranges projected in this study. Also, caution should be used in applying these projections where forest management activities have taken place since the projections are based on succession after fire; particularly in the case of the < 20 years age class. Should future research within the MMF find

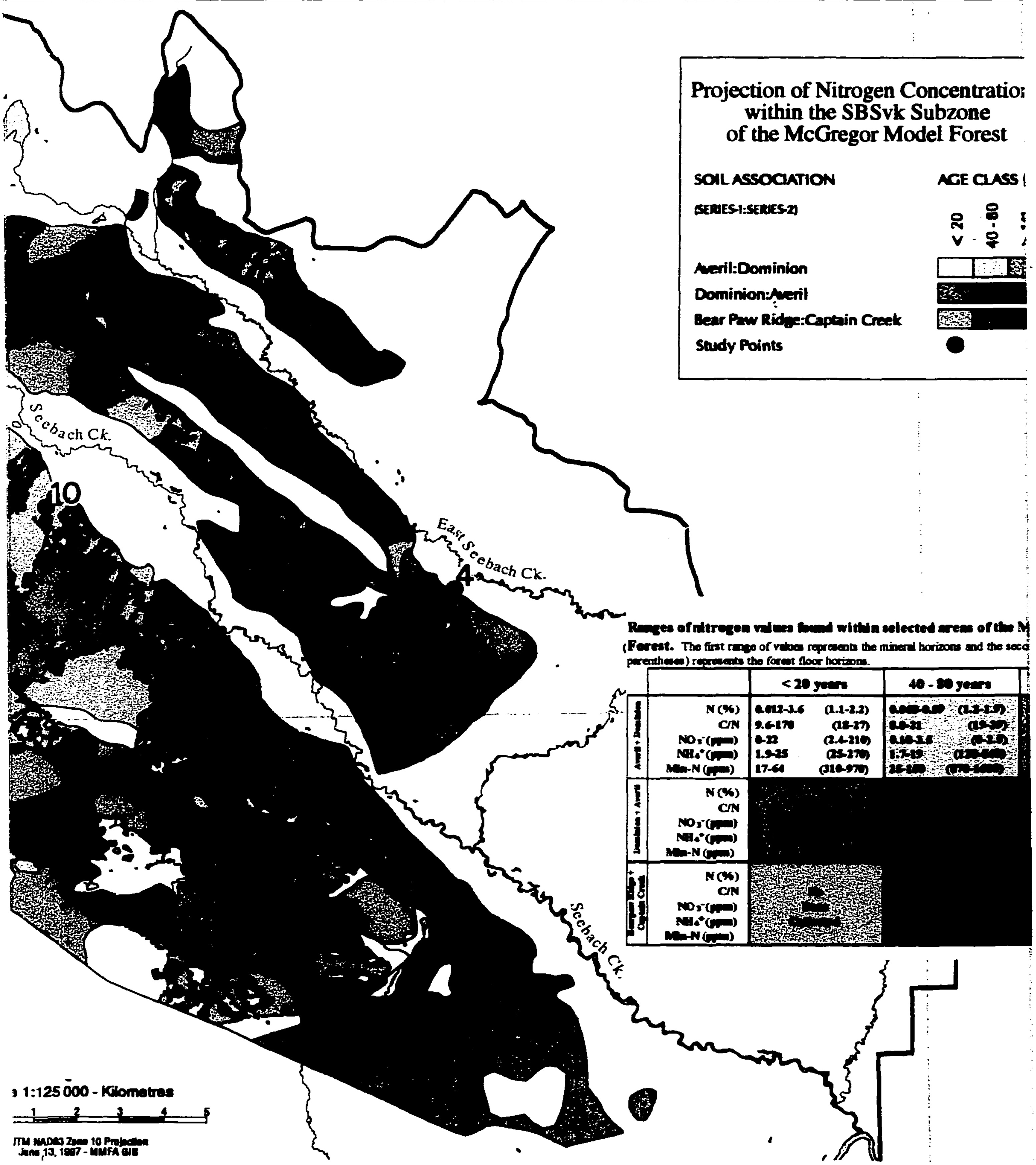
Table 5.22 Areal coverage of nitrogen projected areas within the MMF.

Soil Complex / Age Class	# of polygons	Area Represented (ha)	% of MMF
Averil + Dominion / Early Seral	591	3432	2
Averil + Dominion / Mid-Seral	46	111	0.1
Averil + Dominion / Late Seral	258	4909	3
Dominion + Averil / Mid-Seral	22	80	0.04
Dominion + Averil / Late Seral	307	9664	5
Bearpaw Ridge + Captain Creek / Mid-Seral	56	702	0.4

similar results to the projections provided herein, a more complete understanding of the nitrogen dynamics in these ecosystems will have been achieved through this research.

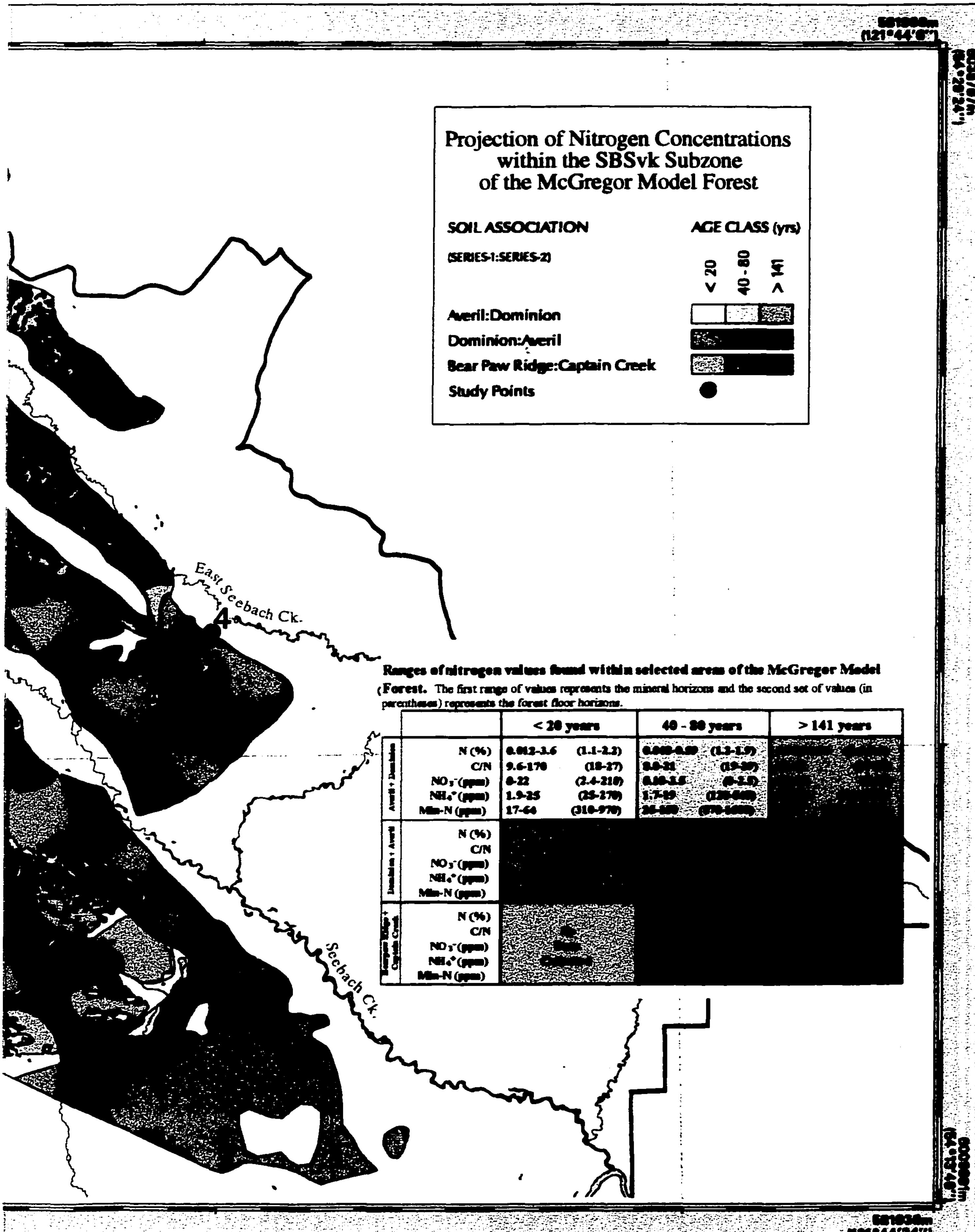
Figure 5.6 Projection of Nitrogen Concentrations within the SBSvk Subzone of the McGregor Mo





Ranges of nitrogen values found within selected areas of the M
Forest. The first range of values represents the mineral horizons and the seco
parentheses) represents the forest floor horizons.

		< 20 years	40 - 80 years
Averil + Dominion	N (%)	0.012-3.6 (1.1-2.2)	[illegible]
	C/N	9.6-170 (18-27)	[illegible]
	NO_3^- (ppm)	0-22 (2.4-210)	[illegible]
	NH_4^+ (ppm)	1.9-25 (25-270)	1.7-19 [illegible]
	Min-N (ppm)	17-64 (310-970)	[illegible]
Dominion + Averil	N (%)	[illegible]	[illegible]
	C/N	[illegible]	[illegible]
	NO_3^- (ppm)	[illegible]	[illegible]
	NH_4^+ (ppm)	[illegible]	[illegible]
	Min-N (ppm)	[illegible]	[illegible]
Bear Paw Ridge + Captain Creek	N (%)	[illegible]	[illegible]
	C/N	[illegible]	[illegible]
	NO_3^- (ppm)	[illegible]	[illegible]
	NH_4^+ (ppm)	[illegible]	[illegible]
	Min-N (ppm)	[illegible]	[illegible]



Ranges of nitrogen values found within selected areas of the McGregor Model Forest. The first range of values represents the mineral horizons and the second set of values (in parentheses) represents the forest floor horizons.

		< 20 years	40 - 80 years	> 141 years
Averil + Dominion	N (%)	0.012-3.6 (1.1-2.2)	0.008-0.89 (1.3-1.9)	[illegible]
	C/N	9.6-170 (18-27)	8.0-21 (19-30)	[illegible]
	NO_3^- (ppm)	0-22 (2.4-210)	0.10-3.5 (0-2.5)	[illegible]
	NH_4^+ (ppm)	1.9-25 (25-270)	1.7-19 ([illegible])	[illegible]
	Min-N (ppm)	17-64 (310-970)	[illegible]	[illegible]
Dominion + Averil	N (%)	[illegible]	[illegible]	[illegible]
	C/N	[illegible]	[illegible]	[illegible]
	NO_3^- (ppm)	[illegible]	[illegible]	[illegible]
	NH_4^+ (ppm)	[illegible]	[illegible]	[illegible]
	Min-N (ppm)	[illegible]	[illegible]	[illegible]
Bearpaw Ridge + Captain Creek	N (%)	[illegible]	[illegible]	[illegible]
	C/N	[illegible]	[illegible]	[illegible]
	NO_3^- (ppm)	[illegible]	[illegible]	[illegible]
	NH_4^+ (ppm)	[illegible]	[illegible]	[illegible]
	Min-N (ppm)	[illegible]	[illegible]	[illegible]

Chapter 6 - SUMMARY AND CONCLUSIONS

In the Central Interior of British Columbia, specific knowledge of the types of soils and their properties is scarce. This deficiency imposes limitations on the short and long term planning for sustainable forest management. Since the end of the last ice age, the Fraser Glaciation, lightning-caused fires have been a major force in determining the structure of the landscape. With fire return intervals in the Sub-boreal Spruce biogeoclimatic zone ranging between 75 and 250 years, an understanding of how they affect nutrient cycling, particularly nitrogen contents, is vital in order to ensure to sustainability of modern forest harvesting practices. This thesis was conducted within the McGregor Model Forest with the objective of providing additional benchmark information on the types and nitrogen content of soils in selected post-fire sites in the SBSvk subzone.

Classification of 15 pedons at 13 study sites reveals the presence of five Eluviated Dystric Brunisols, two Gleyed Eluviated Dystric Brunisols, five Orthic Humo-Ferric Podzols, two Orthic Gray Luvisols and one Rego Humic Gleysol. Podzolization seems to be the dominant pedogenic process in the area along with clay movement (lessivage) and minor hydromorphic processes. Four of the Eluviated Dystric Brunisols - Pedons 1, 3, 4 and 11 (upper slope) - are believed to be the result of incipient podzolization and, with time, are expected to develop into Orthic Humo-Ferric Podzols. The sandy parent materials, cool temperatures and high precipitation rates provide a mechanism conducive to the translocation of organic acids with or without Fe and Al into the B horizon. Lessivage is the dominant process in the two Orthic Gray Luvisols - Pedons 5 and 11 (upper slope) - and is shown to be in the early stages in Pedon 12. The fifth Eluviated Dystric Brunisol - Pedon 12 - should develop into an Orthic Gray Luvisol as it has been formed on different parent material than the other Brunisols. Hydromorphic processes result in the formation of Gleysols and gleyed features - Pedons 6, 10 and 11 (lower slope). These three gleyed pedons resulted from changes in microtopography. The Rego Humic Gleysol, in particular, was formed on colluvium at the base of a relict avalanche which was responsible for the poor drainage and high level of organic matter found.

The 13 sites were categorized into three age classes based on the length of time which had passed since the last forest fire: Early Seral (four sites < 14 years post-fire), Mid-Seral (five sites 50 - 80 years post-fire) and Late Seral (four sites > 140 years post-fire). Total N results compared well to other studies which have been carried out in or near the MMF. No significant differences were found in Total N among the different seral classes indicating that any post-fire effects were no longer present after 14 years. Available NO_3^- levels were found to be higher in the Early Seral age class compared to the Mid-Seral and Late Seral age classes. Available NH_4^+ levels were highest in the Mid-Seral age class for the forest floor and highest in the Late Seral age class for the mineral soil, but were consistently lowest in the Early Seral age class. Mineralizable N values were significantly lower in the Early Seral age class compared to the Mid-Seral and Late Seral age classes. Significant differences in mineralizable N, available NO_3^- and available NH_4^+ levels over time indicated that nitrogen availability changes with stand succession after fire within the SBSvk subzone of the MMF. It was suspected that changes in vegetation species was the dominant factor controlling the nitrogen levels since it controls the chemical and physical characteristics of the organic matter deposited to the forest floor and controls what chemicals are subsequently leached into the mineral horizons. It could not be proven that vegetation establishment and development were the result of variations in nitrogen status, or if the opposite were true (i.e. the vegetation caused the variability found in the nitrogen levels) or, in fact, if both were true. The relationship between specific types of vegetation and the levels of the various types of soil nitrogen needs further research if a model for field assessment of ecosystem nitrogen status is to be produced.

A GIS was used to integrate the nitrogen results from this study with soil survey and forest age class coverages. Superimposing the two coverages allows the research conducted within this study to be placed in a larger spatial context than at the point level in which the data was collected. When used in conjunction with other GIS-based forest management data, these nitrogen projections should provide insight to help guide future forest management decisions. However, the predicted nitrogen levels should be verified by further soil analysis because of the natural spatial heterogeneity of soils.

6.1 Forest Management Implications

There are three main aspects of this thesis which can benefit forest management in the SBSvk. Firstly, the soil classification and its link to the available soil survey data provided baseline information on the types of soils found in the region, as well as their physical, chemical and morphological properties. This thesis also confirmed that the pedons classified were among the possible soil types listed within the soil survey reports. Properties such as the soil texture (percent content of sand or clay, in particular) are useful in rights-of-way planning and slope stability analyses. Secondly, the use of a GIS in projecting nutrient values demonstrates the ability of forest practitioners to increase the number of possible scenarios when conducting short and long term planning. For example, this study projected possible levels of nitrogen in selected forest areas of different ages. Finally, more data has been determined for the nutrient status of soils in the SBSvk.

When considering planting seedlings following wildfire, adjustments can be made to the choice of tree species and fertilizers to be used based on the species' particular nitrogen requirements.

6.2 Recommendations

This study has found shortcomings in the availability and completeness of soil information within this region. The following are some suggested areas where further research would be beneficial.

1. Since the levels of mineralizable nitrogen are much higher in this biogeoclimatic subzone than other areas of British Columbia (and indeed other areas of the SBS) knowledge of the rate of nitrogen cycling within the ecosystem would further add to the understanding of nutrient cycling, in general. Also, examination of the effects of climate change on this potentially large nitrogen pool could provide insight into the possible nutrient status of the future of the SBSvk.
2. In order to address the problems associated with the limitations of single measurements of very labile nutrients (i.e. NO_3^- and NH_4^+), long-term plots should be established from which chemical changes may be monitored over time. As well, these long-term plots will provide information useful to the understanding of nutrient dynamics in the SBSvk.
3. Vegetation/soil nitrogen relationships within the SBS should be studied in depth. By better understanding the nitrogen pathways through a plant's life cycle, it would be easier to determine site productivity and nutrient status from field-based vegetation inventories.
4. An analysis of the variations in vegetative succession (species compositions over time) in the SBS following different types of forest disturbances (i.e. fire or harvesting) would allow for

better predictions of the status of soil nitrogen, etc. as vegetation is the primary source of nutrient input.

5. Ground truthing of the GIS projections of the different nitrogen levels presented in this thesis would provide confirmation of the validity of its use. As well, an assessment of the same procedure in predicting the levels of other nutrient levels (i.e. exchangeable cations and other nutrients required by plants) in the study areas.

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APPENDIX B

Profile Descriptions, Diagnostic Horizons and/or Properties

and Classification of Pedons

2, 3, 4, 6, 7, 8, 10, 11 (upper slope), 11 (middle slope), 12, 13

Pedon 2 - Profile Description.

Horizon	Depth (cm)	Description
S		Bryophytes.
Ln	9-7	Deciduous leaves, coniferous needles, twigs, fungal mycelia.
Fm	7-1	Moist; very dusky red (2.5YR 2.5/2 m); weak, compact matted, loose, acerose; few, fine roots; few, clustered fungal mycelia.
Hr	1-0	Moist; (5YR 2.5/2 m); strong, granular, loose, gritty; common, fine roots; few, random droppings; common, random fungal mycelia.
Ae	0-19	Gray (7.5YR 5/1 m); loamy sand; single grain; loose; plentiful, very coarse, vertical, exped roots; charcoal fragments; clear, smooth boundary.
Bf1	19-32	Brown (7.5YR 4/4 m); silty sand; moderate, fine to medium, subangular blocky; friable; gradual, smooth boundary.
Bf2	32-50	Dark brown (7.5YR 3/3 m); loamy sand; moderate, fine to medium, subangular blocky; friable; gradual, smooth boundary.
BC	50-61	Dark brown (10YR 3/3 m); loamy sand; moderate, fine to medium, subangular blocky; friable; clear, smooth boundary.
C	61+	Olive brown (2.5Y 4/3 m); sand; massive; firm.

Classification, Diagnostic Horizons and/or Properties.

Canadian System: *Orthic Humo-Ferric Podzol.*
Podzolic B horizon.
Bf at least 10 cm thick.
Organic C = 0.5-5%
Fe_p+Al_p = 0.6% or more.

U.S. Soil Taxonomy: *Typic Haplocryod.*
Epipedon: Ochric
Subsurface horizons: Albic, Spodic.
Subsurface materials: Albic, Spodic.

Pedon 3 - Profile Description.

Horizon	Depth (cm)	Description
Ln	6-4	Deciduous leaves, coniferous needles, bryophytes, twigs, fungal mycelia.
Fm	4-2	Moist; (black (10YR 2/1 m); moderate, compact matted, friable, mushy; few, fine roots; common, random fungal mycelia.
Hh	2-0	Moist; black (10YR 2/1 m); strong, compact matted, friable, mushy; common, very fine roots; abundant, random fungal mycelia.
Ae	0-10	Dark gray (10YR 4/1 m); loamy sand; moderate, medium, subangular blocky breaking into single grain; friable; abundant, medium to coarse, vertical, exped roots; clear, smooth boundary.
Bfj1	10-24	Dark yellowish brown (10YR 4/6 m); loamy sand; moderate to strong, fine, subangular blocky breaking into single grain; friable; plentiful, medium to coarse, vertical, exped roots; clear, smooth boundary.
Bfj2	24-34	Dark yellowish brown (10YR 3/4 m); sand; single grain; loose; few, fine to medium, vertical, exped roots; gradual, smooth boundary.
BC	34-46	Olive brown (2.5Y 4/4 m); sand; single grain; loose; very few, fine to medium, vertical, exped roots; gradual, smooth boundary.
C	46+	Dark yellowish brown (10YR 3/4 m); single grain; loose; very few, vertical, exped roots.

Classification, Diagnostic Horizons and/or Properties.

Canadian System: *Eluviated Dystric Brunisol.*

Bfj horizon.
pH < 5.5 by 0.01M $CaCl_2$.
Eluvial horizon at least 2 cm thick.

U.S. Soil Taxonomy: *Typic Cryochrept.*

Epipedon: Ochric
Subsurface horizons: Albic.
Subsurface materials: Albic, Cambic.

Pedon 4 - Profile Description.

Horizon	Depth (cm)	Description
S		Bryophytes.
Ln	5-4	Deciduous leaves, twigs, coniferous needles.
Fa	4-1	Moist; very dark brown (7.5YR 2.5/2 m); moderate non-compact matted, loose, fibrous; abundant, fine roots; few *Collembola*; few, random fungal mycelia.
Hh	1-0	Moist; very dark brown (10YR 2/2 m); strong, granular, friable, gritty; abundant, very fine roots; few *Lumbricida*, few *Collembola*; few, random droppings; few, random fungal mycelia.
Ae	0-6	Gray (7.5YR 6/1 m); silt loam; moderate to strong, fine to medium, subangular blocky; slightly friable; abundant, medium and coarse, horizontal, exped roots; charcoal fragments between LFH and Ae; presence of weathering rock fragments (~ 2-50 mm in diameter) with Fe oxides; clear, wavy boundary.
Bm1	6-22	Strong brown (7.5YR 4/6 m); clay loam; moderate, fine to medium, subangular blocky; friable; plentiful, fine and medium, random, exped roots; gradual, smooth boundary.
Bm2	22-42	Dark brown (7.5YR 3/3 m); clay loam; moderate, medium, subangular blocky; friable; plentiful, medium, horizontal, exped roots; gradual, smooth boundary.
BC	42-58	Brownish yellow (10YR 6/8 m); clay loam; moderate, medium to coarse, subangular blocky; firm; few, fine to medium, vertical, exped roots; gradual, smooth boundary.
C	58+	Yellowish brown (10YR 5/6 m); clay loam; massive; very few, fine to medium, vertical, exped roots; abundant weathering of rocks with Fe oxides.

Classification, Diagnostic Horizons and/or Properties.

Canadian System: *Eluviated Dystric Brunisol.*
Bm horizon.
pH < 5.5 by 0.01M $CaCl_2$.
Eluvial horizon at least 2 cm thick.

U.S. Soil Taxonomy: *Typic Haplocryod.*
Epipedon: Ochric
Subsurface horizons: Albic, Spodic.
Subsurface materials: Albic, Spodic.

Pedon 6 - Profile Description.

Horizon	Depth (cm)	Description
S		Bryophytes.
Ln	4-3	Deciduous leaves, twigs.
Fm	3-0	Moist; black (10YR 2/1 m); weak, compact matted, friable, fibrous; common, very fine roots, common, random fungal mycelia.
Ae	0-20	Gray (10YR 6/1 m); sandy loam; moderate, fine to coarse, granular; friable; abundant, medium to coarse, random, exped roots; clear, wavy boundary.
Btjg	20-45	Dark brown (7.5YR 3/3 m); loam; few, medium, distinct, strong brown (7.5YR 5/8 m) mottles; moderate to strong, medium, subangular blocky; slightly friable; plentiful, medium, vertical, exped roots; gradual, wavy boundary.
Cg	45	Light olive brown (2.5 Y 5/4 m); sandy loam; few, medium, distinct, strong brown (7.5 YR 4/6 m) mottles; massive; slightly friable; very few, fine to medium, vertical, exped roots.

Classification, Diagnostic Horizons and/or Properties.

Canadian System: *Gleyed Eluviated Dystric Brunisol.*
Btjg horizon at least 5 cm thick.
Ae horizon at least 2 cm thick.
pH < 5.5 by 0.01M $CaCl_2$ in upper 25 cm of B horizon.
Mottles.

U.S. Soil Taxonomy: *Typic Cryaquod.*
Epipedon: Ochric
Subsurface horizons: Albic, Spodic.
Subsurface materials: Albic, Spodic.

Other Site Characteristics:
Aquic conditions.
Redoximorphic features.

Pedon 7 - Profile Description.

Horizon	Depth (cm)	Description
S		Bryophytes.
Lv	3-2	Twigs, coniferous needles, fungal mycelia.
Hr	2-0	Moist; very dark brown (10YR 2/2 m); weak, massive, friable, fibrous; common, very fine roots; few *Collembola*; few, random fungal mycelia.
Ae	0-17	Grayish brown (10YR 5/2 w); loamy sand; weak, medium, subangular blocky breaking into single grain; non-sticky, non-plastic; abundant, fine to medium, vertical, exped roots; clear, smooth boundary.
Bf	17-36	Dark brown (7.5YR 3/3 m); loamy sand; moderate, fine to medium, subangular blocky; friable; plentiful, medium, vertical, exped roots; gradual, smooth boundary.
IC	36-65	Dark yellowish brown (10YR 3/4 m); loamy sand; massive; friable; very few, medium, vertical, exped roots.
IIC	65+	Gravel deposit

Classification, Diagnostic Horizons and/or Properties.

Canadian System: *Orthic Humo-Ferric Podzol.*

Podzolic Bf horizon.
Organic C = 0.5-5%
Fe_p+Al_p = 0.6% or more.
Base saturation < 50%

U.S. Soil Taxonomy: *Typic Haplocryod.*

Epipedon: Ochric
Subsurface horizons: Albic, Spodic.
Subsurface materials: Albic, Spodic.

Pedon 8 - Profile Description.

Horizon	Depth (cm)	Description
Lv	8-5	Coniferous needles, twigs, coniferous cones, fungal mycelia.
Fa	5-4	Moist; dark reddish brown (5YR 2.5/2 m); moderate, non-compact matted, friable, fibrous; few, fine roots; few *Coleoptera*; few, random fungal mycelia.
Hh	4-0	Moist; very dark brown (7.5YR 2.5/2 m); weak, granular, firm, gritty; common, very fine roots; few *Lumbricida;* common, random droppings; few, random fungal mycelia.
Ae	0-18	Gray (7.5YR 6/1 m); sandy loam; moderate, medium, subangular blocky; very friable; abundant, coarse to medium, vertical and abundant, coarse, horizontal and vertical, exped roots; clear, smooth boundary.
Bf	18-48	Dark brown (7.5YR 3/4 m); loam; moderate, fine to medium, subangular blocky; friable; abundant, medium, random, exped roots; gradual, smooth boundary.
BC	48-56	Dark yellowish brown (10YR 3/6 m); sandy loam; moderate, medium, subangular blocky; slightly friable; plentiful, fine, medium, vertical, exped roots; clear, smooth boundary.
C	56+	Brown (7.5YR 5/4 m); silty clay loam; massive; firm; very few, fine, vertical, exped roots.

Classification, Diagnostic Horizons and/or Properties.

Canadian System: Podzolic Bf horizon. Organic C = 0.5-5% Fe_p+Al_p = 0.6% or more. Base saturation < 50%	*Orthic Humo-Ferric Podzol.*
U.S. Soil Taxonomy: Epipedon: Ochric Subsurface horizons: Albic, Spodic. Subsurface materials: Albic, Spodic.	*Typic Haplocryod.*

Pedon 10 - Profile Description.

Horizon	Depth (cm)	Description
Lv	6-3	Coniferous needles, twigs, deciduous leaves, spruce cones.
Fm	3-1	Moist; very dark brown (7.5YR 2.5/2 m); moderate, compact matted, friable, fibrous; common, very fine roots; few, random fungal mycelia.
Hh	1-0	Moist; very dark brown (10YR 2/2 m); moderate, compact matted, friable, greasy; common, very fine roots; few, random fungal mycelia.
Ae	0-8	Grayish brown (10YR 5/2 m); silt loam; weak to moderate, medium, subangular blocky; slightly friable; plentiful, medium, vertical, exped roots; charcoal fragments; gradual, wavy boundary.
AB (dis-continuous)	8-13	Brown (10YR 5/3 m); silty clay loam; strong, medium, subangular blocky; friable; plentiful, medium to coarse, vertical, exped roots; gradual, smooth boundary.
Bfj	13-34	Dark yellowish brown (10YR 3/4 m); silty clay loam; moderate, medium, subangular blocky; friable; plentiful, medium and coarse, vertical, exped roots; clear, smooth boundary.
Cg	34+	Olive brown (2.5Y 4/4 m); silt loam; few, medium to coarse, distinct, dark reddish brown (5YR 3/4 m) mottles; massive; slightly friable.

Classification, Diagnostic Horizons and/or Properties.

Canadian System:	*Gleyed Eluviated Dystric Brunisol.*
Bfj horizon.	
pH < 5.5 by 0.01M $CaCl_2$ in B horizon.	
Ae horizon at least 2 cm thick.	
Mottles.	
U.S. Soil Taxonomy:	*Oxyaquic Cryochrept.*
Epipedon: Ochric	
Subsurface horizons: Albic, Cambic.	
Subsurface materials: Albic.	
Other Site Characteristics:	
Aquic conditions.	
Redoximorphic features.	

Pedon 11 (upper slope) - Profile Description.

Horizon	Depth (cm)	Description
Ln	4-2	Deciduous leaves, coniferous needles, fungal mycelia.
Fa	2-0	Moist; dark reddish brown (5YR 2.5/2); moderate, non-compact matted, firm, fibrous; abundant, very fine roots; common, banded fungal mycelia.
Ae	0-2	Gray (2.5Y 6/1 m); silt loam; strong, fine, subangular blocky; friable; few, fine and medium, random, exped roots; abrupt, smooth boundary; 1-3 cm thick.
Bt	2-16	Strong brown (7.5YR 4/6 m); silt loam; strong, fine, subangular blocky; friable; few very fine and coarse; random, exped roots; gradual, smooth boundary; 8-18 cm thick.
BC	16-27	Brown (10YR 5/3 m); silty clay loam; strong, fine, subangular blocky; friable; few very fine and coarse, random, exped roots; gradual, smooth boundary; 7-13 cm thick.
C	27+	Brown (10YR 4/3 m); silt loam; moderate, medium, subangular blocky; firm; few, very fine, random, exped roots.

Classification, Diagnostic Horizons and/or Properties.

Canadian System: *Orthic Gray Luvisol.*
Bt and eluvial horizons.
Chroma < 3 in Ae horizon.

U.S. Soil Taxonomy: *Typic Haplocryod.*
Epipedon: Ochric
Subsurface horizons: Albic, Argillic, Cambic, Spodic.
Subsurface materials: Albic, Spodic.

Pedon 11 (middle slope) - Profile Description.

Horizon	Depth (cm)	Description
Ln	6-4	Deciduous leaves, coniferous needles, spruce cones, fungal mycelia, droppings, *Arachnida*.
Fa	4-0	Moist; very dark brown (7.5YR 2.5/3 m); moderate, non-compact matted, friable, leafy; abundant, very fine roots; few *Arachnida;* common, random droppings; common, random fungal mycelia.
Ae	0-26	Light gray (5YR 7/1 m); silt loam; strong, fine, subangular blocky; loose; few, fine, horizontal, inped roots; clear, irregular boundary; 12-26 cm thick.
Bfj1	26-41	Dark yellowish brown (10YR 3/4 m); silt loam; weak, fine, subangular blocky; friable; plentiful, very fine, horizontal, inped roots; clear, smooth boundary; 13-15 cm thick.
Bfj2	41-56	Yellowish red (5YR 4/6 m); silt loam; weak, fine, subangular blocky; very friable; few, fine, oblique, inped roots; clear, smooth boundary; 10-15 cm thick.
BC	56-75	Dark yellowish brown (10YR 4/6 m); silt loam; moderate, fine, subangular blocky; friable; few, fine, horizontal, inped toots; clear, smooth boundary; 17-19 cm thick.
IIC (dis-continuous)	75-81	Olive brown (2.5Y 4/4 m); silty clay loam; moderate, very fine, granular; very friable; very few, fine, random, inped roots; clear, smooth boundary; 0-8 cm thick.
IC	81+	Strong brown (7.5YR 4/6 m); loam; strong, fine, angular blocky; loose; very few, fine, random, exped roots.

Classification, Diagnostic Horizons and/or Properties.

Canadian System: *Eluviated Dystric Brunisol.*
Bfj horizon.
pH < 5.5 by 0.01M $CaCl_2$ in B horizon.
Ae horizon at least 2 cm thick.

U.S. Soil Taxonomy: *Typic Haplocryod.*
Epipedon: Ochric
Subsurface horizons: Albic, Spodic.
Subsurface materials: Albic, Spodic.

Pedon 12 - Profile Description.

Horizon	Depth (cm)	Description
S		Bryophytes.
Ln	3-2	Coniferous needles, deciduous leaves, fungal mycelia, *Arachnida*.
Fm	2-0	Moist; dark brown (7.5YR 3/3 m); strong, non-compact matted, friable, acerose; few, fine roots; few *Arachnida*; abundant, random fungal mycelia.
Ae	0-14	Pinkish gray (7.5YR 6/2 m); silt loam; moderate to strong, fine, subangular blocky; friable; plentiful, fine, horizontal, inped roots; clear, wavy boundary.
Bfj	14-48	Dark red (2.5YR 4/6 m); loam; moderate to strong, fine, subangular blocky; very friable; plentiful, fine, random, inped roots; clear, wavy boundary.
C	48+	Dark brown (7.5YR 3/3 m); loam; strong, fine, subangular blocky; loose; few, very fine, oblique, exped roots.

Classification, Diagnostic Horizons and/or Properties.

Canadian System: *Eluviated Dystric Brunisol.*
Bfj horizon at least 5 cm thick..
pH < 5.5 by 0.01M $CaCl_2$ in B horizon.
Ae horizon at least 2 cm thick.

U.S. Soil Taxonomy: *Typic Haplocryod.*
Epipedon: Ochric
Subsurface horizons: Albic, Spodic.
Subsurface materials: Albic, Spodic.

Pedon 13 - Profile Description.

Horizon	Depth (cm)	Description
S		Bryophytes and lichen.
Ln	14-11	Deciduous leaves, twigs, mycorrhizae, grasses.
Fa	11-7	Moist; black (10YR 2/1); moderate, non-compact matted, friable, mushy; plentiful, very fine roots; few, random droppings; few, random fungal mycelia.
Hh	7-0	Moist; black (10YR 2/1); weak, compact matted, friable, mushy; abundant, very fine roots; few, random fungal mycelia.
Ahe	0-16	Dark yellowish brown (10YR 4/4 m); silt loam; moderate, fine, subangular blocky; very friable; common, very fine, random, inped and exped roots; clear, wavy boundary; 16-25 cm thick.
AB	16-34	Dark yellowish brown (10YR 3/4 m); silt loam; moderate to strong, fine, subangular blocky; friable; few, medium, random, exped roots; clear, wavy boundary; 12-18 cm thick.
Bf	34-59	Brown (7.5YR 4/4 m); loam; weak, medium, subangular blocky; firm; few, coarse, oblique, exped roots; clear, wavy boundary; 15-27 cm thick.
C	59+	Dark yellowish brown (10YR 4/6 m); loam; moderate, coarse, subangular blocky; firm; few, coarse, oblique, exped roots.

Classification, Diagnostic Horizons and/or Properties.

Canadian System: Podzolic Bf horizon. Organic C = 0.5-5% Fe_p+Al_p = 0.6% or more. Base saturation < 50%	*Orthic Humo-Ferric Podzol.*
U.S. Soil Taxonomy: Epipedon: Ochric Subsurface horizons: Cambic. Subsurface materials: None.	*Typic Cryochrept.*

APPENDIX C

Selected Physical and Chemical Properties

of Pedons

2, 3, 4, 6, 7, 8, 10, 11 (upper slope), 11 (middle slope), 12, 13

Pedon 2 - Selected physical and chemical properties.

HORIZON	Sand %	Clay %	Silt %	Texture Class	C %	N %	C/N	pH dH_2O	pH 0.01M $CaCl_2$
Ae	66.2	3.20	30.6	sandy loam	0.81	0.047	17	4.5	3.6
Bf1	59.8	3.20	36.9	sandy loam	2.1	0.090	23	5.0	4.1
Bf2	58.5	3.40	38.1	sandy loam	2.1	0.091	23	5.4	4.3
BC	66.0	2.40	31.6	sandy loam	1.7	0.082	21	5.5	4.6
C	67.4	4.60	28.0	sandy loam	0.68	0.042	16	6.1	5.1

HORIZON	Extractable Cations by NH_4OAc pH 7.0 (cmol(+)kg^{-1})								Base Sat.
	Al	Ca	Fe	K	Mg	Mn	Na	CEC	%
Ae	0.022#	1.3	0.011#	0.0050#	0.22	0.0070#	0.020	3.9	39
Bf1	0.19	0.99	0.011#	0.028	0.25	0.0070#	0.020	4.9	26
Bf2	0.22	1.1	0.011#	0.088	0.20	0.0070#	0.033	3.4	42
BC	0.28	1.9	0.011#	0.0050#	0.28	0.0070#	0.024	3.7	61
C	0.045	1.8	0.011#	0.0050#	0.27	0.0070#	0.044	2.7	79

HORIZON	Al_p %	Fe_p %	Al_o %	Fe_o %	ODOE*	Fe_p+Al_p	(Fe_p+Al_p)/clay	org C/Fe_p	$.5Fe_o+Al_o$
Ae	0.010	0.0060	0.055	0.025	1.1	0.016	0.0050	133	0.067
Bf1	0.19	0.50	0.31	0.34	1.4	0.69	0.21	4.15	0.48
Bf2	0.20	0.31	0.40	0.22	1.7	0.50	0.15	6.84	0.51
BC	0.15	0.14	0.34	0.12	1.4	0.29	0.12	12.1	0.40
C	0.025	0.047	0.18	0.047	0.32	0.072	0.016	14.6	0.18

$_o$ = $(NH_4)_2C_2O_4$ $_p$ = $Na_4P_2O_7$ * = optical density of oxalate extract # = result lower than this detection limit

Pedon 3 - Selected physical and chemical properties.

HORIZON	Sand %	Clay %	Silt %	Texture Class	C %	N %	C/N	pH dH_2O	pH 0.01M $CaCl_2$
Ae	67.6	6.40	26.0	sandy loam	2.6	0.13	20	4.4	3.6
Bfj1	69.1	6.60	24.4	sandy loam	3.5	0.18	19	4.7	4
Bfj2	95.8	1.00	3.18	sand	2.7	0.11	25	5.1	4.3
BC	97.5	0.700	1.76	sand	3.1	0.095	32	5.2	4.5
C	94.8	0.800	4.41	sand	1.7	0.082	20	5.3	4.5

HORIZON	Extractable Cations by NH_4OAc pH 7.0 (cmol(+)kg^{-1})								Base Sat.
	Al	Ca	Fe	K	Mg	Mn	Na	CEC	%
Ae	0.31	0.82	0.041	0.14	0.42	0.063	0.029	8.0	18
Bfj1	0.55	0.33	0.049	0.0050#	0.18	0.015	0.019	4.9	11
Bfj2	0.43	0.14	0.028	0.025	0.044	0.0070#	0.017	1.9	12
BC	0.24	0.10	0.011#	0.15	0.021	0.0070#	0.036	1.3	23
C	0.34	0.11	0.011#	0.0050#	0.018	0.0070#	0.013	2.0	7.1

HORIZON	Al_p %	Fe_p %	Al_o %	Fe_o %	ODOE*	$Fe_p + Al_p$	$(Fe_p + Al_p)$ /clay	org C/Fe_p	$.5Fe_o + Al_o$
Ae	0.065	0.15	0.11	0.26	1.8	0.22	0.034	17	0.24
Bfj1	0.21	0.33	0.44	0.35	2.2	0.54	0.082	10	0.62
Bfj2	0.11	0.093	0.51	0.16	1.7	0.20	0.20	28	0.58
BC	0.098	0.063	0.55	0.13	1.6	0.16	0.23	49	0.62
C	0.13	0.088	0.46	0.13	1.0	0.22	0.27	19	0.53

$_o = (NH_4)_2C_2O_4$ $_p = Na_4P_2O_7$ * = optical density of oxalate extract # = result lower than this detection limit

Pedon 4 - Selected physical and chemical properties.

HORIZON	Sand %	Clay %	Silt %	Texture Class	C %	N %	C/N	pH dH_2O	pH 0.01M $CaCl_2$
Ahe	30.7	15.2	54.1	silt loam	1.4	0.10	14	4.2	3.5
Bm1	29.9	15.4	54.7	silt loam	1.3	0.25	5.2	4.5	3.8
Bm2	38.1	16.4	45.5	loam	1.0	0.096	10	5.1	4.1
BC	48.5	16.2	35.3	loam	0.48	0.24	2.0	5.2	4.2
C	60.4	18.6	21.0	sandy loam	0.31	0.048	6.4	5.5	4.4

HORIZON	Extractable Cations by NH_4OAc pH 7.0 (cmol(+)kg^{-1})								Base Sat.
	Al	Ca	Fe	K	Mg	Mn	Na	CEC	%
Ae	0.022#	2.0	0.011#	0.19	0.90	0.038	0.023	6.9	45
Bm1	0.17	0.45	0.011#	0.0060	0.31	0.048	0.027	6.1	13
Bm2	0.56	0.17	0.011#	0.10	0.077	0.026	0.014	3.8	9.5
BC	0.27	0.75	0.011	0.0050#	0.20	0.021	0.030	3.6	27
C	0.025	2.7	0.011#	0.0050#	0.39	0.026	0.030	5.4	58

HORIZON	Al_p %	Fe_p %	Al_o %	Fe_o %	ODOE*	Fe_p+Al_p	(Fe_p+Al_p)/clay	org C/Fe_p	$.5Fe_o+Al_o$
Ae	0.0090	0.032	0.025	0.056	0.32	0.041	0.0030	43	0.053
Bm1	0.075	0.27	0.11	0.29	0.64	0.35	0.023	4.7	0.26
Bm2	0.10	0.12	0.22	0.12	0.33	0.22	0.014	8.2	0.28
BC	0.072	0.064	0.091	0.041	0.050	0.14	0.0080	7.5	0.11
C	0.035	0.036	0.036	0.045	0.030	0.071	0.0040	8.5	0.059

$_o$ = $(NH_4)_2C_2O_4$ $_p$ = $Na_4P_2O_7$ * = optical density of oxalate extract # = result lower than this detection limit

Pedon 6 - Selected physical and chemical properties.

HORIZON	Sand %	Clay %	Silt %	Texture Class	C %	N %	C/N	pH dH_2O	pH 0.01M $CaCl_2$
Ae	57.9	4.80	37.4	sandy loam	1.4	0.074	19	5.3	4.5
Btjg	51.5	7.20	41.3	sandy loam	2.0	0.25	7.9	5.5	4.9
Cg	56.4	4.60	39.0	sandy loam	0.62	0.044	14	6.2	5.1

HORIZON	Extractable Cations by NH_4OAc pH 7.0 (cmol(+)kg^{-1})								Base Sat.
	Al	Ca	Fe	K	Mg	Mn	Na	CEC	%
Ae	0.022#	4.1	0.011#	0.0050#	1.4	0.0090	0.016	5.9	93
Btjg	0.022#	6.7	0.011#	0.053	2.3	0.0070#	0.022	8.9	$1.0x10^2$
Cg	0.022#	2.8	0.011#	0.12	0.87	0.0070#	0.010	3.9**	71**

HORIZON	Al_p %	Fe_p %	Al_o %	Fe_o %	ODOE*	Fe_p+Al_p	(Fe_p+Al_p) /clay	org C/Fe_p	$.5Fe_o+Al_o$
Ae	0.017	0.029	0.036	0.061	0.78	0.046	0.010	48	0.067
Btg	0.058	0.25	0.11	0.27	1.6	0.30	0.042	8.1	0.24
Cg	0.024	0.052	0.037	0.043	0.29	0.076	0.017	12	0.058

$_o = (NH_4)_2C_2O_4$ $_p = Na_4P_2O_7$ * = optical density of oxalate extract ** = CEC by summation.
= result lower than this detection limit

Pedon 7 - Selected physical and chemical properties.

HORIZON	Sand %	Clay %	Silt %	Texture Class	C %	N %	C/N	pH dH_2O	pH 0.01M $CaCl_2$
Ae	69.1	2.80	28.1	sandy loam	0.78	0.060	13	4.3	3.5
Bf	73.8	5.20	21.0	sandy loam	2.7	0.10	27	4.4	3.7
C	78.3	2.60	19.1	loamy sand	2.3	0.11	20	4.6	4.1

HORIZON	Extractable Cations by NH_4OAc pH 7.0 (cmol(+)kg^{-1})								Base Sat.
	Al	Ca	Fe	K	Mg	Mn	Na	CEC	%
Ae	0.022#	1.2	0.011#	0.24	0.15	0.012	0.035	2.6	60
Bf	0.12	0.43	0.064	0.12	0.094	0.028	0.011	5.9	11
C	0.30	0.16	0.031	0.033	0.030	0.010	0.014	2.8	8.5

HORIZON	Al_p %	Fe_p %	Al_o %	Fe_o %	ODOE*	Fe_p+Al_p	(Fe_p+Al_p)/clay	org C/Fe_p	$.5Fe_o+Al_o$
Ae	0.0010	0.0040	0.0090	0.010	0.090	0.0050	0.0020	$1.9x10^2$	0.014
Bf	0.18	0.41	0.40	0.53	2.9	0.59	0.11	6.7	0.66
C	0.15	0.14	0.49	0.26	1.6	0.29	0.11	16	0.62

$_o = (NH_4)_2C_2O_4$ $_p = Na_4P_2O_7$ * = optical density of oxalate extract # = result lower than this detection limit

Pedon 8 -Selected physical and chemical properties.

HORIZON	Sand %	Clay %	Silt %	Texture Class	C %	N %	C/N	pH dH_2O	pH 0.01M $CaCl_2$
Ae	56.7	2.40	40.9	sandy loam	0.58	0.045	13	4.3	3.5
Bf	63.3	1.80	34.9	sandy loam	2.9	0.13	23	4.6	4
BC	61.6	2.00	36.4	sandy loam	1.8	0.076	23	4.9	4.2
C	52.0	8.00	40.0	loam/ sandy loam	0.37	0.040	9.3	5.2	4.3

HORIZON	Extractable Cations by NH_4OAc pH 7.0 (cmol(+)kg^{-1})								Base Sat.
	Al	Ca	Fe	K	Mg	Mn	Na	CEC	%
Ae	0.022#	1.0	0.011#	0.065	0.16	0.012	0.0090	2.3	55
Bf	0.012	1.8	0.067	0.065	0.11	0.020	0.047	5.2	39
BC	0.40	0.60	0.011	0.0050#	0.061	0.0090	0.018	3.0	23
C	0.18	0.41	0.011#	0.026	0.094	0.0070#	0.013	1.4	38

HORIZON	Al_p %	Fe_p %	Al_o %	Fe_o %	ODOE*	Fe_p+Al_p	(Fe_p+Al_p)/clay	org C/Fe_p	$.5Fe_o+Al_o$
Ae	0.0020	0.0080	0.0090	0.016	0.24	0.011	0.0050	69	0.017
Bf	0.12	0.53	0.24	0.77	2.9	0.65	0.36	5.6	0.63
BC	0.18	0.12	0.43	0.23	1.6	0.30	0.15	15	0.55
C	0.061	0.046	0.10	0.040	0.060	0.11	0.013	8.1	0.12

$_o = (NH_4)_2C_2O_4$ $_p = Na_4P_2O_7$ * = optical density of oxalate extract # = result lower than this detection limit

Pedon 10 - Selected physical and chemical properties.

HORIZON	Sand %	Clay %	Silt %	Texture Class	C %	N %	C/N	pH dH_2O	pH 0.01M $CaCl_2$
Ae	28.9	6.60	64.5	silt loam	0.88	0.060	15	4.5	3.8
AB	30.0	10.0	60.0	silt loam	0.74	0.062	12	4.6	3.9
Bfj	41.7	7.40	50.9	silt loam	0.75	0.11	7.1	4.8	4
Cg	37.9	6.00	56.1	silt loam	1.0	0.076	14	5.1	4.2

HORIZON	Extractable Cations by NH_4OAc pH 7.0 (cmol(+)kg^{-1})								Base Sat.
	Al	Ca	Fe	K	Mg	Mn	Na	CEC	%
Ae	0.022#	2.8	0.011#	0.0050#	0.64	0.0070#	0.014	5.3	65
AB	0.016	2.2	0.011#	0.12	0.68	0.0070#	0.028	5.8	52
Bfj	0.097	2.0	0.033	0.098	0.83	0.0070#	0.047	7.1	42
Cg	0.33	0.50	0.020	0.031	0.21	0.0090	0.021	2.4	32

HORIZON	Al_p %	Fe_p %	Al_o %	Fe_o %	ODOE*	Fe_p+Al_p	(Fe_p+Al_p) /clay	org C/Fe_p	$.5Fe_o+Al_o$
Ae	0.007	0.025	0.019	0.035	0.34	0.032	0.0050	35	0.036
AB	0.014	0.051	0.031	0.084	0.33	0.065	0.0070	14	0.073
Bfj	0.097	0.35	0.17	0.37	1.5	0.44	0.060	2.2	0.35
Cg	0.089	0.097	0.20	0.13	0.54	0.19	0.031	11	0.26

$_o = (NH_4)_2C_2O_4$ $_p = Na_4P_2O_7$ * = optical density of oxalate extract # = result lower than this detection limit

Pedon 11 (upper slope) - Selected physical and chemical properties.

HORIZON	Sand %	Clay %	Silt %	Texture Class	C %	N %	C/N	pH dH_2O	pH 0.01M $CaCl_2$
Ae	41.1	7.90	51.0	silt loam	0.87	0.055	16	4.3	3.5
Bt	30.5	13.4	56.1	silt loam	1.8	0.11	17	4.4	3.8
BC	39.5	8.70	51.8	silt loam	1.1	0.064	18	4.7	4.1
C	39.6	8.60	51.9	silt loam	0.31	0.016	19	4.7	4.2

HORIZON	Extractable Cations by NH_4OAc pH 7.0 (cmol(+)kg^{-1})								Base Sat.
	Al	Ca	Fe	K	Mg	Mn	Na	CEC	%
Ae	0.022#	1.9	0.011#	0.0050#	0.45	0.060	0.031	6.9	34
Bt	0.36	1.1	0.15	0.15	0.26	0.045	0.020	7.0	23
BC	0.29	0.35	0.011#	0.0050#	0.079	0.020	0.0080	2.9	15
C	0.21	0.25	0.011	0.096	0.062	0.016	0.010	1.6	27

HORIZON	Al_p %	Fe_p %	Al_o %	Fe_o %	ODOE*	Fe_p+Al_p	(Fe_p+Al_p)/clay	org C/Fe_p	$.5Fe_o+Al_o$
Ae	0.0090	0.018	0.029	0.028	0.10	0.027	0.0030	48	0.043
Bt	0.11	0.40	0.19	0.51	1.7	0.51	0.038	4.5	0.45
BC	0.083	0.12	0.18	0.16	0.53	0.20	0.023	9.6	0.25
C	0.046	0.061	0.081	0.063	0.10	0.11	0.012	5.1	0.11

$_o = (NH_4)_2C_2O_4$ $_p = Na_4P_2O_7$ * = optical density of oxalate extract # = result lower than this detection limit

Pedon 11 (middle slope) - Selected physical and chemical properties.

HORIZON	Sand %	Clay %	Silt %	Texture Class	C %	N %	C/N	pH dH_2O	pH 0.01M $CaCl_2$
Ae	50.1	4.80	45.1	sandy loam	0.36	0.030	12	4.4	3.6
Bfj1	76.3	5.40	18.4	loamy sand/ sandy loam	0.98	0.049	20	4.8	4.2
Bfj2	70.3	5.20	24.5	sandy loam	1.2	0.056	21	5.1	4.3
BC	83.4	2.10	14.5	loamy sand	1.1	0.055	20	5.2	4.5
IIC	27.4	10.4	62.2	silt loam	0.54	0.032	17	5.3	4.5
IC	91.8	0.700	7.50	sand	1.0	0.049	21	5.6	4.7

HORIZON	Extractable Cations by NH_4OAc pH 7.0 (cmol(+)kg^{-1})								Base Sat.
	Al	Ca	Fe	K	Mg	Mn	Na	CEC	%
Ae	0.12	1.42	0.012	0.089	0.11	0.026	0.068	4.9	34
Bfj1	0.14	0.96	0.025	0.063	0.079	0.029	0.011	3.1	36
Bfj2	0.30	0.46	0.014	0.0050#	0.046	0.010	0.032	1.8	31
BC	0.28	0.17	0.011#	0.069	0.020	0.0070#	0.013	1.1	25
IIC	0.39	0.32	0.011#	0.079	0.035	0.0070#	1.9	2.7**	85
C	0.24	0.18	0.011#	0.029	0.018	0.0070#	0.0090	1.1	22

HORIZON	Al_p %	Fe_p %	Al_o %	Fe_o %	ODOE*	Fe_p+Al_p	(Fe_p+Al_p)/clay	org C/Fe_p	$.5Fe_o+Al_o$
Ae	0.010	0.018	0.020	0.038	0.10	0.029	0.0060	20	0.039
Bfj1	0.10	0.36	0.17	0.23	0.55	0.47	0.086	2.7	0.29
Bfj2	0.13	0.21	0.25	0.16	0.56	0.34	0.065	5.6	0.33
BC	0.17	0.20	0.30	0.14	0.51	0.37	0.17	5.4	0.37
IIC	0.089	0.079	0.18	0.076	0.14	0.17	0.016	6.9	0.21
C	0.15	0.17	0.29	0.14	0.42	0.32	0.46	6.0	0.36

$_o$ = $(NH_4)_2C_2O_4$ $_p$ = $Na_4P_2O_7$ * = optical density of oxalate extract ** = CEC by summation.
= results lower than this detection limit

Pedon 12 - Selected physical and chemical properties.

HORIZON	Sand %	Clay %	Silt %	Texture Class	C %	N %	C/N	pH dH_2O	pH 0.01M $CaCl_2$
Ae	62.2	3.90	33.9	sandy loam	0.88	0.067	13	3.9	3.3
Bfj	83.9	1.40	14.7	loamy sand	2.3	0.12	20	4.8	4.1
C	89.1	1.40	9.50	sand	1.5	0.075	19	5.2	4.4

HORIZON	Extractable Cations by NH_4OAc pH 7.0 (cmol(+)kg^{-1})								Base Sat.
	Al	Ca	Fe	K	Mg	Mn	Na	CEC	%
Ae	0.27	1.1	0.026	0.0070	0.22	0.028	0.020	5.8	23
Bfj	0.25	0.85	0.050	0.028	0.13	0.017	0.0090#	2.9	34
C	0.33	0.55	0.015	0.041	0.072	0.011	0.0090#	1.8	36

HORIZON	Al_p %	Fe_p %	Al_o %	Fe_o %	ODOE*	Fe_p+Al_p	(Fe_p+Al_p) /clay	org C/Fe_p	$.5Fe_o+Al_o$
Ae	0.026	0.036	0.050	0.069	0.26	0.063	0.016	24	0.085
Bfj	0.11	0.23	0.28	0.48	1.9	0.34	0.24	10	0.52
C	0.17	0.16	0.39	0.23	1.4	0.33	0.23	9.4	0.51

$_o = (NH_4)_2C_2O_4$ $_p = Na_4P_2O_7$ * = optical density of oxalate extract # = result lower than this detection limit

Pedon 13 - Selected physical and chemical properties.

HORIZON	Sand %	Clay %	Silt %	Texture Class	C %	N %	C/N	pH dH_2O	pH 0.01M $CaCl_2$
Ahe	48.2	9.20	42.6	loam	1.7	0.077	21	4.2	3.5
AB	47.3	10.4	42.3	loam	2.7	0.13	22	6.7	6.0
Bf	51.7	9.60	38.7	loam/ sandy loam	2.2	0.11	21	7.2	6.4
C	55.9	7.80	36.3	sandy loam	2.4	0.14	18	7.1	6.3

HORIZON	Extractable Cations by NH_4OAc pH 7.0 (cmol(+)kg^{-1})								Base Sat.
	Al	Ca	Fe	K	Mg	Mn	Na	CEC	%
Ahe	0.33	3.9	0.10	0.21	0.67	0.042	0.040	12	40
AB	0.022#	18	0.011#	0.081	2.9	0.025	0.019	18	1.2×10^2
Bf	0.022#	17	0.011#	0.090	2.0	0.018	0.031	15	1.1×10^2
C	0.022#	12	0.011#	0.052	1.5	0.014	0.035	12	1.1×10^2

HORIZON	Al_p %	Fe_p %	Al_o %	Fe_o %	ODOE*	Fe_p+Al_p	(Fe_p+Al_p)/clay	org C/Fe_p	$.5Fe_o+Al_o$
Ahe	0.075	0.34	0.11	0.44	2.6	0.42	0.045	4.8	0.33
AB	0.11	0.46	0.14	0.29	2.1	0.57	0.054	5.9	0.28
Bf	0.11	0.58	0.11	0.24	1.1	0.69	0.072	3.8	0.23
C	0.20	0.52	0.26	0.19	1.0	0.72	0.092	4.6	0.35

$_o = (NH_4)_2C_2O_4$ $_p = Na_4P_2O_7$ * = optical density of oxalate extract # = result lower than this detection limit

APPENDIX D

Complete Data Set from Nitrogen Analyses.

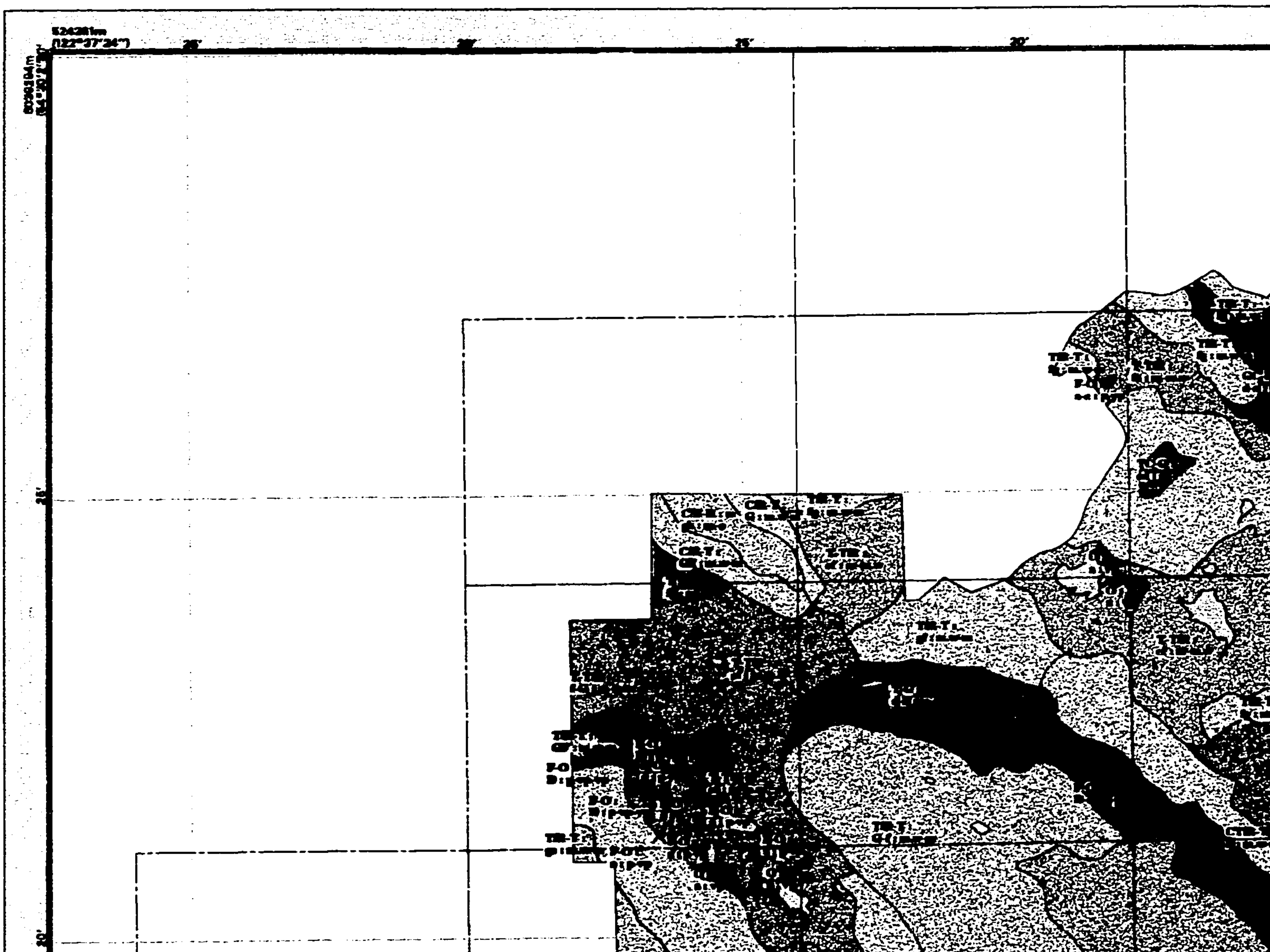
Sample #	Site #	Horizon	C	N	C/N	NO_3^-	NH_4^+	min-N
			%	%		ppm	ppm	ppm
64	1	Ahe	2.441	0.135	18.081	0.40	8.00	42
65	1	Ahe	2	0.093	21.505	0.15	7.25	36.4
116	1	Ahe	2.733	0.101	27.059	0.45	6.65	30.8
117	1	Ahe	1.877	0.047	39.936	0.15	6.60	25.2
68	2	Ae	2.4	0.129	18.605	5.15	12.25	25.2
69	2	Ae	1.745	0.081	21.543	3.15	12.45	16.8
120	2	Ae	2.553	0.089	28.685	4.25	8.55	25.2
121	2	Ae	1.633	0.134	12.187	2.60	7.95	22.4
72	3	Ae	3.269	0.187	17.481	0.10	13.35	28
73	3	Ae	3.509	0.19	18.468	0.10	8.80	25.2
124	3	Ae	2.956	0.134	22.060	0.00	10.90	30.8
125	3	Ae	3.306	0.29	11.400	0.00	9.65	22.4
76	4	Ae	3.512	0.197	17.827	1.45	24.30	42
77	4	Ae	2.248	0.123	18.276	0.10	22.05	36.4
128	4	Ae	3.637	0.314	11.583	0.80	15.85	30.8
129	4	Ae	2.222	0.098	22.673	0.20	22.15	47.6
80	5	Ae	2.026	0.012	168.833	0.45	13.25	33.6
81	5	Ae	2.299	0.132	17.417	0.15	25.30	53.2
132	5	Ae	1.431	0.062	23.081	0.10	8.40	30.8
133	5	Ae	3.315	0.16	20.719	0.00	14.90	30.8
84	6	Ae	1.501	0.071	21.141	11.60	6.30	36.4
85	6	Ae	1.51	0.064	23.594	12.40	9.05	30.8
136	6	Ae	1.998	0.084	23.786	5.75	1.95	19.6
137	6	Ae	1.169	0.042	27.833	10.60	4.95	16.8
88	7	Ae	1.145	0.068	16.838	0.75	13.55	28
89	7	Ae	1.017	0.062	16.403	0.60	19.25	145.6
140	7	Ae	1.013	0.048	21.104	0.25	6.05	30.8
141	7	Ae	1.202	0.068	17.676	0.10	8.80	28
92	8	Ae	3.371	0.146	23.089	7.40	11.70	28
93	8	Ae	2.605	0.108	24.120	9.05	19.60	42
144	8	Ae	2.321	0.106	21.896	5.35	9.00	30.8
145	8	Ae	2.722	0.042	64.810	6.20	16.20	39.2
96	9	Ae	1.103	0.048	22.979	0.30	6.20	16.8
97	9	Ae	1.029	0.048	21.437	0.25	8.35	16.8
148	9	Ae	2.164	0.109	19.853	0.15	3.15	16.8
149	9	Ae	0.871	0.215	4.051	0.00	3.35	28
100	10	Ae	2.278	0.076	29.974	0.35	19.50	33.6
101	10	Ae	1.933	0.108	17.898	12.15	13.30	33.6
152	10	Ae	2.597	0.04	64.925	0.10	10.20	42
153	10	Ae	2.455	0.042	58.452	6.60	6.55	39.2
104	11	Ae	1.519	0.091	16.692	1.75	11.30	28

105	11	Ae	1.418	0.081	17.506	0.15	10.35	22.4
156	11	Ae	1.057	0.055	19.218	0.60	5.35	39.2
157	11	Ae	1.057	0.055	19.218	0.00	4.55	19.6
108	12	Ae	2.516	ND (.01)	ERR	0.25	9.80	28
109	12	Ae	1.92	0.242	7.934	0.15	11.80	22.4
160	12	Ae	2.339	0.115	20.339	0.00	3.90	25.2
161	12	Ae	2.593	0.139	18.655	0.00	6.15	36.4
112	13	Ahe	4.467	0.258	17.314	13.55	7.85	39.2
113	13	Ahe	3.687	0.209	17.641	9.80	5.90	16.8
164	13	Ahe	5.426	0.178	30.483	10.85	5.85	39.2
165	13	Ahe	2.486	0.131	18.977	8.20	4.25	22.4
66	1	Bf	2.549	0.14	18.207	4.70	6.15	47.6
67	1	Bf	2.762	0.306	9.026	3.20	6.80	61.6
118	1	Bf	2.774	0.094	29.511	5.60	5.95	14
119	1	Bf	2.785	0.103	27.039	3.80	5.80	58.8
70	2	Bf	2.676	0.111	24.108	6.20	13.10	44.8
71	2	Bf	3.288	0.303	10.851	1.70	15.30	53.2
122	2	Bf	2.752	0.242	11.372	7.85	7.65	39.2
123	2	Bf	3.728	0.323	11.542	1.40	13.95	36.4
74	3	Bf	2.679	0.317	8.451	0.15	8.90	22.4
75	3	Bf	4.487	0.275	16.316	0.20	7.80	25.2
126	3	Bf	2.687	0.132	20.356	0.05	7.10	22.4
127	3	Bf	4.296	0.225	19.093	0.00	5.60	19.6
78	4	Bt	2.266	0.138	16.420	0.95	7.95	22.4
79	4	Bt	1.762	0.112	15.732	2.35	10.05	22.4
130	4	Bt	2.27	0.119	19.076	0.85	5.15	25.2
131	4	Bt	2.064	0.116	17.793	1.90	6.25	16.8
82	5	Bt	3.689	0.097	38.031	0.10	13.50	56
83	5	Bt	3.42	0.356	9.607	22.00	5.45	36.4
134	5	Bt	3.793	0.189	20.069	0.00	7.10	36.4
135	5	Bt	2.736	0.146	18.740	15.90	2.15	25.2
86	6	Bt	2.364	0.128	18.469	12.20	6.45	64.4
87	6	Bt	2.496	0.127	19.654	14.05	4.10	33.6
138	6	Bt	2.226	0.103	21.612	9.55	3.85	39.2
139	6	Bt	2.418	0.116	20.845	11.45	1.85	33.6
90	7	Bf	4.338	0.457	9.492	2.10	9.20	25.2
91	7	Bf	3.933	0.229	17.175	3.50	7.65	25.2
142	7	Bf	3.213	0.333	9.649	0.85	1.65	28
143	7	Bf	4.77	0.593	8.044	1.20	2.95	33.6
94	8	Bf	3.611	0.2	18.055	27.55	8.70	72.8
95	8	Bf	4.701	0.261	18.011	23.75	9.10	78.4
146	8	Bf	2.722	0.042	64.810	19.50	5.05	84
147	8	Bf	3.599	0.181	19.884	23.85	10.20	78.4

98	9	Bf	3.3	0.161	20.497	14.50	8.15	58.8
99	9	Bf	3.266	0.161	20.286	16.05	11.00	44.8
150	9	Bf	2.507	0.114	21.991	9.75	4.55	56
151	9	Bf	3.298	0.15	21.987	8.60	4.65	50.4
102	10	Bf	1.788	0.067	26.687	10.60	8.50	22.4
103	10	Bf	2.654	0.145	18.303	11.75	9.75	30.8
154	10	Bf	2.152	0.104	20.692	9.50	5.70	30.8
155	10	Bf	2.548	0.139	18.331	9.65	7.00	33.6
106	11	Bf	1.405	0.099	14.192	1.10	6.10	25.2
107	11	Bf	2.803	0.155	18.084	3.20	7.70	25.2
158	11	Bf	1.604	0.082	19.561	0.30	1.80	25.2
159	11	Bf	2.283	0.102	22.382	1.75	2.50	36.4
110	12	Bf	2.372	0.133	17.835	0.10	6.75	11.2
111	12	Bf	3.245	0.184	17.636	0.20	11.45	50.4
162	12	Bf	2.626	0.127	20.677	0.00	2.00	16.8
163	12	Bf	3.299	0.158	20.880	0.05	6.75	50.4
114	13	Bf	2.345	0.094	24.947	7.40	3.15	44.8
115	13	Bf	2.919	0.138	21.152	8.55	4.10	53.2
166	13	Bf	2.24	0.086	26.047	6.40	1.40	33.6
167	13	Bf	3.675	0.203	18.103	7.10	2.15	53.2
168	1	L	40.12	1.48	27.108	0.95	85.00	966
170	1	L	43.84	2.27	19.313	6.40	314.17	868
173	1	L	37.25	1.12	33.259	9.75	128.00	770
176	2	L	46.08	1.72	26.791	1.15	346.60	1036
179	2	L	41.25	1.46	28.253	0.40	34.05	812
182	2	L	34.9	1.24	28.145	2.70	259.30	658
185	3	L	42.93	2.27	18.912	1.55	538.30	2044
188	3	L	43.56	2.02	21.564	0.35	23.25	1036
191	3	L	41.21	1.67	24.677	0.20	24.40	1358
193	4	L	39.5	1.4	28.214	0.45	131.83	588
195	4	L	40.27	1.65	24.406	0.40	126.90	1190
197	4	L	38.62	1.81	21.337	0.35	35.75	1638
203	6	L	45.28	1.88	24.085	49.45	255.10	784
205	6	L	39.55	2.17	18.226	83.98	81.00	910
207	7	L	31.57	1.4	22.550	2.50	494.17	1358
209	7	L	35.09	1.2	29.242	0.00	124.87	868
212	7	L	44.91	1.85	24.276	2.20	268.00	1428
214	8	L	43.99	1.63	26.988	3.70	248.50	1624
218	9	L	19.5	0.802	24.314	36.50	332.25	462
220	9	L	31.15	1.17	26.624	5.00	390.90	1078
222	9	L	38.28	0.735	52.082	1.40	121.10	462
225	10	L	40.04	0.534	74.981	164.87	178.00	574
228	10	L	37.81	1.56	24.237	39.30	464.10	728

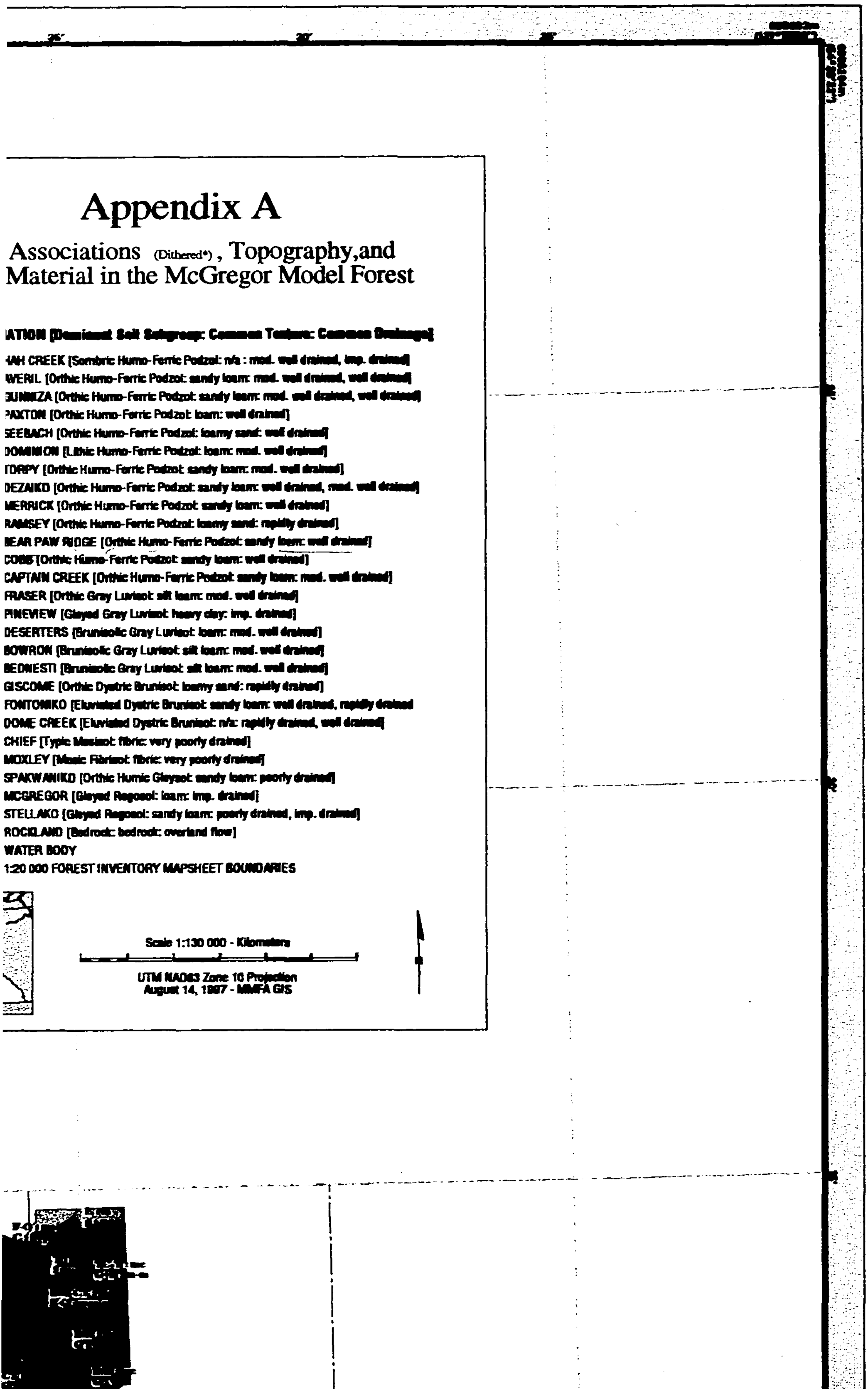
231	10	L	46.58	1.46	31.904	76.65	275.90	770
234	11	L	38.87	1.45	26.807	0.46	123.68	714
237	12	L	47.23	1.35	34.985	0.20	108.30	434
240	12	L	36.98	1.38	26.797	0.90	220.70	462
245	13	L	43.57	2.15	20.265	180.46	39.30	476
248	13	L	42.7	2.21	19.321	122.56	102.79	560
171	1	F	44.37	2.62	16.935	2.90	89.70	1442
174	1	F	39.05	1.61	24.255	26.95	111.60	1134
177	2	F	46.22	1.67	27.677	0.70	478.70	1078
180	2	F	44.49	1.76	25.278	0.30	95.70	1232
183	2	F	45.45	1.6	28.406	1.25	230.60	560
184	2	H	30.3	1.1	27.545	0.40	248.80	476
186	3	F	41.54	2.19	18.968	0.80	333.20	1708
189	3	F	40.27	2.01	20.035	0.65	121.00	1596
201	5	L+F	41.36	1.94	21.320	40.706	132.50	378
206	6	F	32.68	1.63	20.049	74.08	96.00	966
208	7	F	31.75	1.71	18.567	1.60	544.80	1554
210	7	F	40.78	1.61	25.329	0.00	389.10	1022
215	8	F	44.54	1.71	26.047	1.50	537.80	1218
223	9	F	44.3	0.446	99.327	2.60	42.60	378
226	10	F	45.78	2.02	22.663	163.95	200.50	616
229	10	F	44.52	1.86	23.935	18.50	553.20	784
232	10	F	40.67	1.76	23.108	87.47	267.80	896
235	11	F	26.57	1.13	23.513	0.30	105.50	1064
236	11	F	39.31	1.73	22.723	1.90	93.50	1540
238	12	F	43.82	1.69	25.929	0.00	69.00	616
241	12	F	35.66	1.7	20.976	0.10	102.50	812
243	12	F	41.44	1.91	21.696	1.20	66.00	826
246	13	F	41.76	2.31	18.078	110.24	44.30	644
250	13	F	40.71	2.05	19.859	119.23	41.50	686
169	1	F+H	42.43	1.66	25.560	0.45	31.45	1176
172	1	H	42.15	2.23	18.901	3.95	146.30	1134
175	1	H	28.99	1.46	19.856	15.65	32.50	630
178	2	H	46.38	1.75	26.503	0.75	647.40	1190
181	2	H	39.84	1.56	25.538	0.40	68.50	630
187	3	H	42.69	2.34	18.244	0.30	109.30	1204
190	3	H	33.38	1.45	23.021	0.30	26.70	854
192	3	F+H	30.02	1.36	22.074	0.55	94.90	672
194	4	F+H	43.38	1.53	28.353	0.30	71.40	504
196	4	F+H	40.77	1.82	22.401	0.60	180.50	938
198	4	F+H	28.89	1.5	19.260	0.70	35.75	1638
199	5	L+F+H	35.01	1.37	25.555	13.90	25.40	616
200	5	L+F+H	29.8	1.09	27.339	2.40	30.30	308

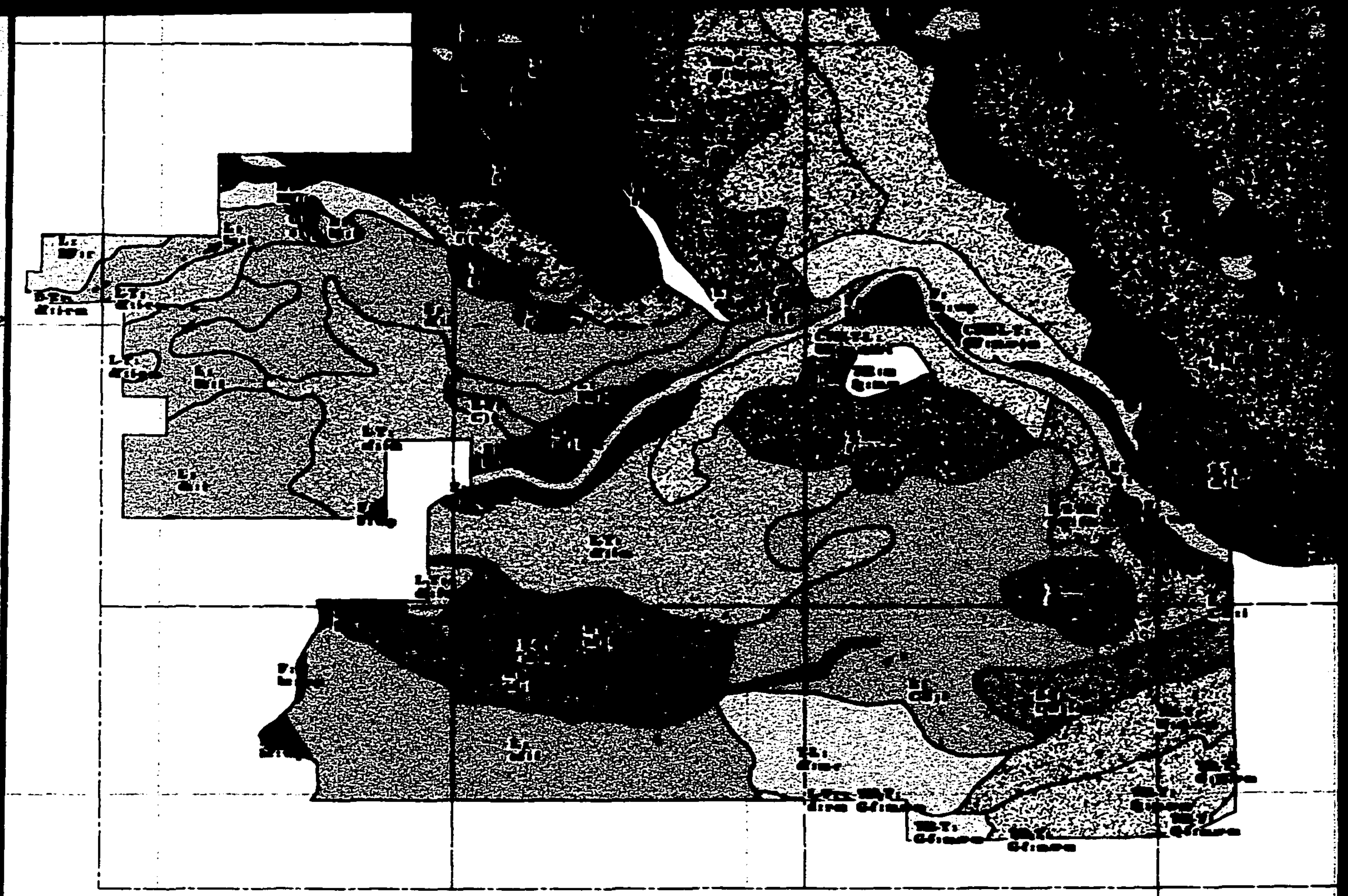
202	6	F+H	38.63	1.92	20.120	209.26	266.00	770
204	6	F+H	43.87	1.76	24.926	40.50	84.00	644
211	7	H	36.75	1.53	24.020	0.00	205.90	1302
213	7	F+H	42.33	1.79	23.648	1.90	514.20	1386
216	8	H	42.96	1.73	24.832	0.00	226.30	1862
217	8	H	45.68	2.41	18.954	67.00	135.50	1778
219	9	F+H	30.2	1.28	23.594	11.10	99.80	336
221	9	H	37.03	1.58	23.437	1.50	318.30	1148
224	9	H	38.9	0.726	53.581	0.50	53.20	406
227	10	H	43.49	2.1	20.710	110.80	164.40	616
230	10	H	37.4	1.56	23.974	13.00	321.40	1036
233	10	H	36.3	2.09	17.368	56.71	222.90	1246
239	12	H	44.07	1.52	28.993	0.00	82.90	952
242	12	H	34.1	1.51	22.583	0.30	51.30	882
244	12	H	37.56	1.47	25.551	0.50	51.50	840
247	13	H	33.31	1.61	20.689	68.97	23.20	434
249	13	H	39.55	2.05	19.293	105.24	29.40	518
251	13	H	27.83	1.65	16.867	50.64	27.10	322


524281m
(122°37'24")
25'
20'

Appendix A

Associations (Dithered*), Topography,and Material in the McGregor Model Forest





Polygon Label Key

XX : xx Common Parent material : Common Texture size
YY : yy Common Topography : Common Drainage

Label Abbrev

Common Parent Material

Symbol		Genetic Material
C	=	colluvial
E	=	eolian
F	=	fluvial
G	=	glaciofluvial
L	=	lacustrine
O	=	organic
R	=	bedrock
T	=	till (morainal)
-	=	and
/	=	overlying

Common Texture Size

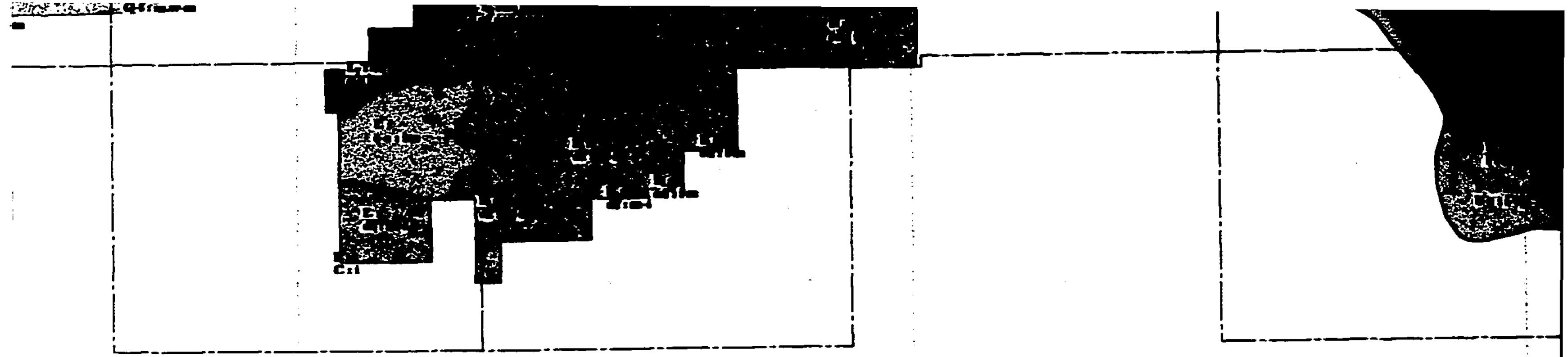
Symbol		Texture Size Class
f	=	fine
m	=	medium
c	=	coarse
/	=	overlying

Common Topography

Symbol		Simple Topography
A	=	depressional to level
B	=	very gently sloping
C	=	gently sloping
D	=	moderately moderately sloping
E	=	strongly sloping
F	=	steeply sloping
G	=	very steeply sloping
H	=	extremely sloping

Symbol		Com
a	=	near
b	=	gent
c	=	und
d	=	gent
e	=	mod
f	=	stro
g	=	hilly
h	=	very

5994476m
(54°0'28")
5342m
(122°37'40")



Label Abbreviations

Common Topography

...y	Symbol		Complex Topography (% slope)
...vel	a	=	nearly level (0-0.5)
...g	b	=	gently undulating (0.5-2)
	c	=	undulating (2-5)
...rately sloping	d	=	gently rolling (5-9)
	e	=	moderately rolling (9-15)
	f	=	strongly rolling (15-30)
...ng	g	=	hilly (30-60)
	h	=	very hilly (60+)

Common Drainage

Symbol		Drainage
o	=	overland flow
r	=	rapidly drained
w	=	well drained
m	=	moderately well drained
i	=	imperfectly drained
p	=	poorly drained
v	=	very poorly drained
-	=	range of site values within the association
.	=	range of values within a site

* Dithered - The prope...
within that polygon. T...
association at that la...
The information for th...
survey reports (BC So...
Original mapping wa...

* Dithered - The proportion of colour drawn within a polygon reflects the percentage of a particular soil association within that polygon. The placement of the colour is random and does not indicate the actual existence of the soil association at that location.
The information for this map was compiled by Kevin Driscoll (University of Northern British Columbia) from soil survey reports (BC Soil Survey Reports 2, 4, 10, 29, 31, 32, 53) and soil surficial geology and landform maps. Original mapping was conducted at 1:100,000 scales and superimposed on 1:50,000 topographic maps.